Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
Unlicensed Use of the 6 GHz Band	)	ET Docket No. 18-295
Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz	)	GN Docket No. 17-183

REPLY COMMENTS OF HEWLETT PACKARD ENTERPRISE

Chuck Lukaszewski
Vice President, Wireless Strategy
Hewlett Packard Enterprise
3333 Scott Boulevard
Santa Clara, CA 95054

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INTRODUCTION AND SUMMARY

Hewlett Packard Enterprise ("HPE") submits these reply comments in response to the Commission's Notice of Proposed Rulemaking ("NPRM") for the 6 GHz band.[1] HPE joins the RLAN Group Reply Comments[2] and submits these comments to focus on issues of particular importance to HPE or where our position as a manufacturer gives us additional insight. The Commission's process of advancing this proceeding through a notice of inquiry ("NOI") and NPRM has produced a record that shows wide-ranging agreement among diverse stakeholders. While comments reveal debate over implementation questions and particular technical rules, fixed service and RLAN commenters agree with the Commission's use of an Automated Frequency Coordination ("AFC") system to protect incumbents from harmful interference[3] and agree that

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1 *Unlicensed Use of the 6 GHz Band*, Notice of Proposed Rulemaking, FCC No. 18-147, ET Docket 18-295 (rel. Oct. 24, 2018) ("6 GHz NPRM").

2 Reply Comments of Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Marvell Semiconductor, Inc., Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company, ET Docket No. 18-295, GN Docket No. 17-183 (filed Mar. 18, 2019) ("RLAN Group Reply Comments").

3 Unless otherwise indicated, all comments referenced herein were filed on Feb. 15, 2019 in ET Docket No. 18-295. *See* Comments of APCO International at 2-3, 5-6 ("APCO Comments"); Comments of Apple Inc. at 4-5 ("Apple Comments"); Comments of the Boeing Company at 12; Comments of Broadcom Inc. at 4, 40 ("Broadcom Comments"); Comments of the City of Los Angeles at 10-11, 13; Comments of the City of New York at 3 ("NYC Comments"); Comments of the Computing Technology Industry Association at 2 ("CompTIA Comments"); Comments of Comsearch at 7-8 ("Comsearch Comments"); Comments of CTIA at 17-18 ("CTIA Comments"); Comments of Dynamic Spectrum Alliance at 9-10, ET Docket No. 18-295 (filed Feb. 19, 2019) ("DSA Comments"); Comments of Ericsson at 20 ("Ericsson Comments"); Comments of the Fixed Wireless Communications Coalition at 13 ("FWCC Comments"); Comments of GE Healthcare at 8 ("GEHC Comments"); Comments of Hewlett Packard Enterprise Company at 22, 27-28 ("HPE Comments"); Comments of Microsoft Corporation at 15-18 ("Microsoft Comments"); Comments of Motorola Solutions Inc. at 2 ("Motorola Comments"); Comments of the National Public Safety Telecommunications Council at 10 ("NPSTC Comments"); Comments of the National Spectrum Management Association at 4-5 ("NSMA Comments"); Comments of NCTA – The Internet & Television Association at 11-12 ("NCTA Comments"); Comments of Nokia at 2 ("Nokia Comments"); Comments of

RLAN interference concerns are limited to situations where an RLAN is operating near the main beam of an FS link.[4] There is also considerable agreement on many fundamental aspects of the operation of an AFC system.[5]

But a small number of commenters, most notably CTIA, Ericsson, and Qualcomm, disagree with the Commission's findings and proposals and ask the FCC to instead adopt flawed and unworkable rules in an effort to favor their technologies over all others. HPE opposes these proposals and supports the Commission's framework. Additionally, HPE requests that the Commission adopt specific operational and technical guidelines to efficiently and safely deploy

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Qualcomm Incorporated at 11-12; Comments of Sony Electronics Inc. at 1-2 ("Sony Comments"); Comments of the Ultra Wide Band Alliance at 8 ("UWB Comments"); Comments of Wi-Fi Alliance at 19.

4 *See* Comments of Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Marvell Semiconductor, Inc., Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company at 27, ET Docket No. 18-295, GN Docket No. 17-183 (filed Feb. 15, 2019) ("RLAN Group Comments"); Broadcom Comments at 9-10; FWCC Comments at 9-10; Nokia Comments at Technical Appendix; Comments of Tucson Electric Power Company and UNS Electric, Inc. at 31.

5 *See* APCO Comments at 14; Comsearch Comments at 26-27; DSA Comments at 13-14; FWCC Comments at 29-30 HPE Comments at 24; Motorola Comments at 4; Comments of the Open Technology Institute at New America, the American Library Association, the Consumer Federation of America, the Consortium for School Networking, Public Knowledge, and Access Humboldt at 27 ("Public Interest Organizations ("PIO") Comments"); Qualcomm Comments at 17; Comments of Teradek, LLC and Amimon, Inc. at 8, 11 ("Teradek/Amimon Comments"); Wi-Fi Alliance Comments at 25-26 (all agreeing regarding flexible geolocation requirements).

See APCO Comments at 10; Apple Comments at 11-13; Broadcom Comments at 43-44; Comsearch Comments at 25-26; DSA Comments at 12; Facebook Comments at 9; Comments of Federated Wireless, Inc. at 11-12; HPE Comments at 25; Microsoft Comments at 20; Motorola Comments at 4-5; Comments of NETGEAR, Inc. at 2, ET Docket No. 18-295 (filed Feb. 13, 2019) ("NETGEAR Comments"); PIO Comments at 26; Comments of Quantenna Communications, Inc. at 5, ET Docket No. 18-295 (filed Feb. 14, 2019) ("Quantenna Comments"); Sony Comments at 7-8; Teradek/Amimon Comments at 6; Wi-Fi Alliance Comments at 26-27; Comments of the Wireless Internet Service Providers Association at 19-20 ("WISPA Comments") (all agreeing that multiple AFC operators can calculate protection zones).

unlicensed technologies in the 6 GHz band, including rules that: (1) strengthen the requirement that licensees must update their information in ULS; (2) create a decentralized AFC system without individual device identifiers; (3) authorize low-power-indoor ("LPI"), very-low-power ("VLP"), and portable access points; (4) permit limited RLAN control signal requests for network attachment; (5) allow point-to-point and point-to-multipoint operation using highly directional antennas; and (6) authorize three-dimensional AFC-calculated protection contours. Finally, the Commission can facilitate co-existence between RLAN devices, including very-low-power devices, and ultra-wideband ("UWB") systems in the 6 GHz band by recognizing that situation-specific coordination, rather than restrictive rules, will allow both classes of unlicensed technology to thrive in the 6 GHz band.

I. THE COMMISSION SHOULD ADOPT ITS PROPOSAL TO AUTHORIZE RLAN OPERATION THROUGHOUT THE 6 GHZ BAND AND SHOULD REJECT CTIA'S AND ERICSSON'S CALLS TO DISPLACE INCUMBENTS.

HPE applauds the Commission for its balanced and forward-looking proposal to open the full 6 GHz band to unlicensed operations and to avoid relocating existing licensed services.[6] A wide group of commenters supports this proposal.

But CTIA opposes the Commission's proposal and argues that the FCC should "relocate point-to-point fixed service and electronic news gathering incumbents."[7] To make room for this forced relocation, CTIA also argues that the Commission should displace federal users from a portion of the 7.125-8.4 GHz band.[8]

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[6] *See* 6 GHz NPRM at ¶¶ 1-2, 19-21.

[7] CTIA Comments at 2, 10.

[8] *See* CTIA Comments at 13.

Ericsson similarly opposes the Commission's proposal and argues that the Commission should conduct a non-voluntary relocation of incumbents from the U-NII-7 and -8 bands and remove government users from the 7.125-8.4 GHz band or convert this band into a shared federal/non-federal band to make room for relocated 6 GHz incumbents.[9]

Both proposals are patently unworkable. They are unsupported by the record, lack even basic analysis, and would delay FCC action for years. HPE strongly opposes CTIA's and Ericsson's proposals and urges the Commission to instead adopt its proposed framework, improved in the manner discussed in our initial comments and the RLAN Group Comments.

A. Unlicensed RLAN operation would keep incumbent licensees in their current bands, whereas the CTIA and Ericsson proposals would force them to relocate.

The FCC's proposal to permit unlicensed RLAN operations throughout the 6 GHz band would result in incumbents remaining in their current bands and being able to grow their networks in the future. RLANs would always have to protect existing or future incumbent operations against harmful interference.[10] But CTIA's and Ericsson's proposals would require the FCC to conduct a forced relocation of incumbent operations. As some commenters note—including CTIA—many current 6 GHz licensees have already been relocated *to* the 6 GHz band.[11] Requiring them to move

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9 Ericsson Comments at 13-15.

10 *See* 47 C.F.R. § 15.5.

11 *See* CTIA comments at 12 (stating that the commission has previously "relocate[d] BAS and CARS operations from spectrum designated for new licensed flexible use services – and it should now propose to apply that framework to the upper 6 GHz band. For example, in 2000, the Commission adopted relocation and cost-sharing rules to clear BAS licensees, which included CARS operations, from the 1990-2110 MHz band."); Comments of the El Paso Electric Company at 2 ("El Paso Electric Comments"); FWCC Comments at 8; Comments of Xcel Energy at 3; Comments of the Utilities Technology Council, Edison Electric Institute, National Rural Cooperative Association, American Public Power Association, American Petroleum Institute, and American Water Works Association at 9, 10 ("Critical Infrastructure Coalition Comments") (noting that "[p]rivate operational fixed microwave licensees have been required to vacate both the 1.9 GHz band and the 2.1 GHz band so the Commission could

again for the benefit of the cellular industry is both inequitable and untenable. Fortunately, this is not necessary. Authorizing RLAN use in the 6 GHz band would not require a move, promoting stability and certainty for incumbent licensees.

Ericsson's response to incumbents concerned about a non-voluntary relocation is telling. They advise incumbents that even if they lose their licensees, they can become 5G customers of mobile operators using Ericsson equipment.[12] We suspect that incumbents will not be reassured. Such a change would impose high recurring charges they do not face today, in addition to a complete equipment replacement. Replacing equipment would be costly, time consuming, and nearly impossible for some operators, which, as FWCC illustrates, have receivers and transmitters in inhospitable and difficult-to-access locations.[13] And many of these locations are in rural areas where it is unlikely that Ericsson and the carriers will deploy 5G services for many years, in which case companies that lose their FS licenses could be left unserved. Unsurprisingly, given the impracticality of the CTIA and Ericsson proposals, numerous commenters urge the Commission to adopt its proposed framework, rather than displace incumbents in favor of licensed mobile services.[14]

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reallocate the spectrum," and explaining that Coalition members have "no viable alternative to their existing 6 GHz networks.").

12 *See* Ericsson Comments at 16 (contending that "in some circumstances it may be most efficient to move BAS and/or CARS facilities to a different transmission medium, e.g., fiber or 5G.")

13 FWCC Comments at 8 fig. 1 (showing an FS site encased in ice), 35 fig. 9 (photo of "Hard-to-access FS location" on an icy, snow-drifted ridge).

14 *See* Qualcomm Comments at 6 ("Qualcomm strongly supports FCC action to open the band for unlicensed broadband use to further feed the wireless connectivity innovation pipeline."); *see also* Apple Comments at 3; NCTA Comments at 6; RLAN Group Comments at 2, 12; WISPA Comments at 6.

B. The 6 GHz band is not an efficient choice for new licensed mobile services.

Even if the CTIA and Ericsson proposals were possible, they would greatly delay Commission action and would be onerous, complicated, and severely disruptive to licensed incumbents. As CTIA and Ericsson note, the Commission is currently conducting a proceeding to clear part of the 3.7-4.2 GHz band for licensed mobile broadband use.[15] Whatever the outcome of that proceeding, the CTIA and Ericsson proposals for licensing parts of the 6 GHz band would take substantially more time to execute because they effectively require relocations in both the 6 GHz band and the 7.125 to 8.4 GHz band, rather than just clearing and repacking one band. Additionally, the 7.125 to 8.4 GHz government-user relocation would require engagement by NTIA and various federal government stakeholders, likely further delaying the process.

Indeed, if speedy access to new licensed frequencies is the goal, then the optimal course would be to pursue frequencies above 7.125 GHz for licensed mobile use and avoid 6 GHz altogether. While HPE does not support this approach, it shows the irrationality of CTIA's and Ericsson's positions because such an approach would cut the time needed to accomplish CTIA's and Ericsson's goal in half. And it would be more efficient to negotiate with a smaller pool of federal incumbents in the 7.125-8.4 GHz band than to negotiate with these users *and* the thousands of discrete entities and dozens of user communities in the 6 GHz band, as CTIA and Ericsson propose.

To the extent proponents of these plans claim that a "bifurcated approach" with unlicensed use in the lower 6 GHz band and licensed use in the upper 6 GHz band would promote

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15 *See* CTIA Comments at 6; Ericsson at 8; *Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, Order and Notice of Proposed Rulemaking, FCC No. 18-91, GN Docket No. 18-122 (Rel. July 13, 2018) ("3.7-4.2 GHz NPRM") (proposing to add a new mobile allocation to the band and clearing all or part of the band for flexible use licensing).

harmonization with the EU,[16] this claim is incorrect. As Ericsson is aware, EU regulators have not decided to split the band in favor of licensed use above 6425 MHz. In fact, not only does the ETSI system reference document for license-exempt RLAN use extend to 6725 MHz,[17] but in February of 2018, seven European administrations including France, Germany, Norway and Sweden "strongly oppose[d] . . .the adoption of the proposed NWI [new work item] for MFCN [mobile/fixed communications networks] in the band 6425 MHz to 7125 MHz."[18] They noted that "[f]ixed links will remain in 6 GHz" and that "6425-7125 MHz . . . are widely used across EU Member States for the deployment of high-capacity fixed links over distances in the range of 30 to 60 km."[19] In June 2018, Norway announced an auction for twenty-five year licenses for the 6440-7100 MHz range, which is channelized for 40 MHz frequency division duplex fixed service in accordance with longstanding ECC rules.[20]

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16 *See* Ericsson Comments at 4 ("In Europe regulators have bifurcated the 6 GHz band, launching unlicensed operations in the 5.925-6.425 GHz band.")

17 *See* ETSI, *System Reference document (SRdoc); Wireless access systems including radio local area networks (WAS/RLANs) in the band 5925 MHz to 6725 MHz* (Oct. 2018), https://www.etsi.org/deliver/etsi_tr/103500_103599/103524/01.01.01_60/tr_103524v010101p.pdf.

18 *See* ETSI, *Opposition to the proposed newWI SRdoc for MFCN in the band 6425 MHz to 7125 MHz, ERM(18) 064072r4* at 1 (Feb. 19, 2018).

19 *Id; see also* ETSI, *Draft ERM#64 Meeting Minutes, ERM(18)064002* at 34-35 (Feb. 19, 2018), (continuing the creation of a formal system reference document and instead opting to pursue an informational technical report instead).

20 *See* NKOM, *Norwegian Communications Authority Award of frequencies in the high 6 GHz, 8 GHz, low 10 GHz, high 10 GHz, 13 GHz, 18 GHz, 23 GHz, 28 GHz and 38 GHz frequency bands* (Jun. 2018), https://www.nkom.no/aktuelt/nyheter/_attachment/35109?_ts=1644a3051e5; *see also* ECC ERC, *Radio-frequency channel arrangements for high, medium and low capacity digital fixed service systems operating in the band 6425 to 7125 MHz: Recommendation 14-02*, (approved in 1995 and revised on Sept. 19, 2014), https://www.ecodocdb.dk/download/5570c6c2-1438/ERCREC1402.PDF.

C. Proposals to set aside 6.425-6.525 GHz for licensed indoor operation are unnecessary and would significantly undermine the robust unlicensed ecosystem the Commission envisions in the band.

As discussed in HPE's comments, and by other commenters, LPI operations will encompass a significant part of unlicensed use in the band and are central to providing chipmakers, equipment companies, and network operators the economic foundation for building, shipping and installing 6 GHz equipment.[21] Because U-NII-6 and -8 are currently the only bands for LPI use proposed by the Commission (though many commenters encourage the Commission to additionally permit LPI operations in U-NII-5 and -7), blocking unlicensed operations by setting aside U-NII-6 for licensed indoor use would be fatal to the success of Wi-Fi and other critical unlicensed uses in the band.[22]

The cellular industry has ample existing spectrum for licensed indoor operation, with more on the way. The challenge cellular providers face is not spectrum availability, but the cost and complexity of the indoor small cell market that results from having dedicated, overlapping small cell equipment layers for each individual mobile operator. According to the Small Cell Forum, the total number of enterprise indoor small cells installed worldwide was no more than 1.35 million in 2017, of which just 292,000 (less than 20%) were in North America.[23] This represents a 44% reduction from their May 2016 forecast and a 55% reduction from their November 2015 forecast.[24] By

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21 Broadcom Comments at 25-27; Comments of Cisco Systems, Inc. at 5-10 ("Cisco Comments"); HPE Comments at 8.

22 *See* Ericsson Comments at 16-19 (asking the Commission to make the 6.425-6.525 GHz frequencies available for licensed indoor use).

23 *See* Small Cell Forum, *Small cells market status report, Document 050.10.02*, at 1 fig. 1, 10 fig. 4-1 (Feb. 2018).

24 *See* Small Cell Forum, *Small cell deployments, Market status report* at "Small cell Shipments" figure for 2017 (projecting approximately 2.4 million small cell shipments in 2017) (May 2016); Small Cell Forum, *Crossing the Chasm: Small Cells Industry* at 6 fig. 2 (predicting approximately three million in enterprise small cell shipments in 2017) (Nov. 2015). *See also* Keith Dyer, *The downs and ups of the*

contrast, the enterprise WLAN industry shipped 17.5 million indoor access points ("APs") in 2017 alone and is growing at an 8% compound annual growth rate. The failure of indoor cellular to achieve market traction has taken a significant toll on the small cell industry. In 2017, most remaining independent small cell manufacturers were dissolved or sold. Indeed, it was widely reported that Cisco shut down its licensed indoor small cell business in 2017.[25]

The unique limits of licensed spectrum are arguably the principal cause of this disappointing performance, especially compared to the enormous growth of unlicensed operations over the same period of time. Requiring enterprises to deploy multiple, separate layers of small cells for each mobile operator—often at densities similar to Wi-Fi—means they must justify spending as much or more as they already have for pervasive Wi-Fi coverage. HPE has conducted extensive private market research on the enterprise small cell opportunity and has found that these financial headwinds are hard to overcome for the simple reason that, today, enterprises do not budget for indoor cellular coverage. While virtually every enterprise, from small businesses to multi-national corporations, allocates annual capital and operating expenditures to their corporate wired and wireless networks, businesses generally do not consider cellular network quality to be their responsibility. To fund a small cell buildout, they would therefore have to transfer funds away from other IT programs. Even for those niche locations such as hospitals, airports, or stadiums that employ distributed antenna systems ("DAS"), the prevailing financing models involve ten- to twenty-year agreements with operator- or third-party-provided capital recovered via carriage fees

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small cell market, The Mobile Network (May 24, 2018), http://the-mobile-network.com/2018/05/the-downs-and-ups-of-the-small-cell-market/.

25 Monica Alleven, *Cisco confirms shutdown of licensed small cell unit*, FierceWireless (Jul. 19, 2017), https://www.fiercewireless.com/wireless/cisco-mum-reports-it-s-shutting-down-small-cell-business.

from other operators. Unlike small cell deployments, DAS agreements are typically cost-neutral to the enterprise.

In addition, enterprises are ill-prepared to negotiate carriage agreements on their own, and their IT departments often lack training and knowledge about cellular technology. Because small cells must be coordinated with the macro network, enterprises are wholly dependent on mobile network operators, whose engineering teams' first priority is to support their own network, not thousands of discrete, private small cell deployments.

Blocking access for unlicensed devices to reserve a band for indoor licensed service will not solve these problems. In fact, these problems with market dynamics are beyond the Commission's ability to solve. Setting aside U-NII-6 for indoor licensed uses is clearly not justified and will merely result in fallowing spectrum that could otherwise be immediately put to productive use by shared technologies. And while Ericsson has not suggested this is the case, it would clearly be inappropriate for the Commission to try to boost struggling indoor licensed equipment by hamstringing Wi-Fi and other alternatives so that enterprises have no option but to buy more expensive and complex small cell systems.

Furthermore, Ericsson's argument that industrial IoT applications will rely on licensed networks rather than unlicensed spectrum is unconvincing.[26] Even Ericsson's own most recent Mobility Report reveals that, although the number of cellular IoT connections is projected to grow, short-range IoT devices, which rely on unlicensed spectrum, currently account for 87% of the IoT connections worldwide (7.5 billion of 8.6 billion).[27] By 2024, Ericsson projects that cellular IoT will

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[26] *See* Ericsson Comments at 17-19.

[27] Ericsson, *Ericsson Mobility Report: Special edition, World Economic Forum* at 11 (Jan. 2019), https://www.ericsson.com/assets/local/mobility-report/documents/2019/ericsson-mobility-report-world-economic-forum.pdf.

still only account for 20% of IoT devices.[28] Further, energy-sensitive IOT devices with small bandwidth requirements need only a few subcarriers and resource blocks at infrequent intervals.

D. Neither CTIA nor Ericsson has presented a coexistence study for licensed cellular operation of the band, and the RKF Study cannot be used for this purpose because it is limited to RLAN coexistence.

Importantly, Ericsson and CTIA fail to provide any technical feasibility study demonstrating that licensed cellular deployments can coexist with BAS and public safety mobile incumbents in U-NII-6, or with the FSS incumbents—which conduct both earth-to-space and space-to-earth operations—that would remain in U-NII-7 and U-NII-8 after any hypothetical relocation of other terrestrial users.[29] There is no other evidence on this topic in the record. The RKF study demonstrates that RLANs and incumbent services can co-exist safely, but it is not applicable to the question of cellular sharing. Because Ericsson has not provided even basic sharing analysis, the Commission should disregard its proposal.

E. The Commission should adopt its proposed allocations of unlicensed and licensed mid-band spectrum.

The Commission has rightly found that there is a pressing need for additional unlicensed spectrum given that "America's appetite for wireless broadband connections can seem insatiable," placing high demand on "systems that rely on unlicensed devices to deliver data to consumers."[30] And fixed and satellite-based licensed services will remain the primary services throughout the entire band even after the FCC permits unlicensed operations. Nonetheless, and despite the Commission's

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28 *See id.*

29 *See* CTIA Comments at 12-13 (contending, without explanation, that "terrestrial operations would not interfere with the operation of the distant satellite" for earth-to-space operations, and that FSS receive earth stations "could be accommodated" using coordination zones); Ericsson Comments at 16 (stating that "Ericsson does not believe that FSS earth stations operating in the earth-to-space direction in the 6.875-7.125 GHz band need protection.").

30 6 GHz NPRM at ¶ 4.

work to open the 600 MHz, 700 MHz, AWS-3, and 3.5 GHz bands for licensed mobile services, and the FCC's work on ongoing proceedings in the 900 MHz and 3.7-4.2 GHz bands to open even more licensed spectrum—all of which occurred since the FCC last opened new unlicensed mid-band spectrum—CTIA argues that the Commission somehow has done too much for unlicensed technologies. In fact, as discussed below, the FCC has conducted 90 auctions for licensed services since it opened the U-NII bands. CTIA and Ericsson ask the Commission to clear incumbents and limit access for unlicensed devices without demonstrating that despite all of the FCC's work on auctions in recent years, the need for more licensed spectrum is greater than the widely acknowledged need for additional spectrum for Wi-Fi and other unlicensed technologies. Multiple commenters in this proceeding have demonstrated that the need for unlicensed frequencies is urgent,[31] and we attach the recent study prepared for the Wi-Fi Alliance on this point for the record as Appendix A.

Ericsson's arguments questioning the FCC's findings on the importance of unlicensed technologies are unconvincing. For example, Ericsson claims that offloading onto unlicensed networks in stadiums is decreasing,[32] but fails to reveal that, in 2017, Wi-Fi/fixed networks carried over twelve times as much traffic per month as mobile networks did,[33] and that Cisco's recent

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31 Boeing Comments at 3–4; Broadcom Comments at 25–26; Comments of Charter Communications, Inc. at 2 ("Charter Comments"); Cisco Comments at 3–8; CompTIA Comments at 1; Facebook Comments at 1–2; Federated Wireless Comments at 2; GEHC Comments at 1, 6; HPE Comments at 3–7; Comments of IEEE 802 at 3, ET Docket No. 18-295 (filed Dec. 12, 2018); Microsoft Comments at 2–4; NCTA Comments at 2, 6–9; PIO Comments at 5–14; Qualcomm Comments at 6–7; Quantenna Comments at 2; Wi-Fi Alliance Comments at 5–9; WISPA Comments at 4–9.

32 Ericsson Comments at 12.

33 *See* Cisco, *Visual Networking Index Forecast Highlights Tool, United States, Wired/Wi-Fi/Mobile Traffic*, https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html#

Mobile Visual Networking Index shows that more than half of all mobile traffic travels over Wi-Fi or small cells rather than licensed cellular networks.[34] Furthermore, in the more specific stadium context, the new Wi-Fi protocol is specifically designed to address denser deployments, and HPE expects that Wi-Fi will continue its critical role in large-venue connectivity.[35] HPE supplied the Wi-Fi system for both Super Bowl 50 and the most recent Super Bowl 53 in Atlanta. Wi-Fi data transmission at Super Bowl 53 exceeded all previous records, moving over 24 terabytes ("TB") of data on the Wi-Fi system, compared with only 11.5 TB for AT&T's network inside the stadium.[36] This Wi-Fi record was an increase from 16.3 TB in 2018 and 11.8 TB in 2017. And, also in its new Mobile VNI, Cisco observes that 5G will actually increase the amount of traffic offloaded to unlicensed spectrum (both Wi-Fi and LAA).[37] The Wireless Infrastructure Association agrees. In a new report published last month, WIA pointedly notes, "[t]he paradox of 5G is that although it

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(showing that, in 2017, Wi-Fi/fixed networks carried 14.7 exabytes of traffic per month, compared to only 1.2 exabytes of traffic per month over mobile data networks).

[34] Cisco, *Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017–2022* at 17 (Feb. 2019), https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-738429.pdf ("Cisco Mobile VNI").

[35] *See, e.g.*, Sean Kinney, *The future of wireless connectivity in stadiums*, RCR Wireless News (Jul. 12, 2018), https://www.rcrwireless.com/20180712/network-infrastructure/wi-fi/future-wireless-connectivity-stadiums-tag17.

[36] Paul Kapustka, *Super Bowl 53 smashes Wi-Fi record with 24 TB of traffic at Mercedes-Benz Stadium*, mobile sports report (Feb. 8, 2019), https://www.mobilesportsreport.com/2019/02/super-bowl-53-smashes-wi-fi-record-with-24-tb-of-traffic-at-mercedes-benz-stadium/; Paul Kapustka, *Super Bowl cellular report: AT&T, Sprint combine for almost 50 TB of game-day traffic*, mobile sports report (Feb. 4, 2019), https://www.mobilesportsreport.com/2019/02/super-bowl-cellular-report-att-sees-11-5-tb-of-traffic-in-and-around-mercedes-benz-stadium/.

[37] *See* Cisco Mobile VNI at 17.

provides more bandwidth, it will also support so much more data usage that even more offload is required."[38]

As noted above, the Commission is already proposing to clear and license part of the 3.7-4.2 GHz band, which will make up to 500 megahertz of licensed mobile 5G spectrum available.[39] Additionally, the Commission has just announced that it will freeze applications for new or expanded radiolocation service operations in the 3100-3500 MHz band after the MOBILE NOW Act directed NTIA and the Commission to consider allowing commercial wireless services to share those frequencies and NTIA announced that it had identified 3450-3550 MHz in particular for potential repurposing for wireless broadband use.[40] In fact, after NTIA's announcement, CTIA requested that the Commission adopt an immediate freeze "on the acceptance, processing, or grant of any non-federal applications in the 3450-3550 MHz band."[41]

The FCC has conducted 90 auctions for various types of spectrum licenses since it opened the 5 GHz band to unlicensed operations in 1997.[42] Each of the licenses awarded companies

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[38] Wireless Infrastructure Association, *The 5G Paradox: The Need for More Offloading Options in the Next-Generation Wireless Era* at 3 (Feb. 8, 2019), https://wia.org/wp-content/uploads/WIA_Offload-web.pdf.

[39] *See* 3.7-4.2 GHz NPRM at ¶¶ 1, 2 (seeking to transition all or part of the band to terrestrial wireless broadband services); *see also* Letter from Steve Sharkey to Marlene Dortch, GN Docket No. 18-122 (filed Feb. 15, 2019) (explaining a refined incentive auction proposal that could make potentially all 500 megahertz of spectrum available in an auction).

[40] *See Temporary Freeze on Non-Federal Applications in the 3100-3550 MHz Band*, Public Notice, DA No. 19-105, WT Docket No. 19-39 (rel. Feb. 22, 2019).

[41] *Id.* at 1 n.4, citing Letter from Scott K. Bergmann, Senior Vice President, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, FCC, at 1, 2 (filed Apr. 27, 2018); *see also* Comments of CTIA at 6, GN Docket No. 14-177 (filed Sept. 11, 2018).

[42] *See Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range*, Report and Order, FCC No. 97-5, ET Docket No. 96-102 (rel. Jan. 9, 1997); Federal Communications Commission, *Auctions Summary: Completed Auctions*, fcc.gov (last accessed: Mar. 8, 2019), https://www.fcc.gov/auctions-summary.

unfettered use in large geographic areas with no sharing responsibilities—a far different proposition than granting RLANs access only when and where any licensed user does not need the band. For this reason, the FCC has been right to reject any idea of megahertz-to-megahertz parity between licensed and unlicensed bands and instead pursue a balanced policy to open more of both to support innovation and the economy.[43]

Additionally, any company, including licensed mobile operators, would have full access to 6 GHz unlicensed spectrum. But the same would not be true in reverse if the Commission awards mobile licenses in the band. Unlicensed spectrum is inherently a neutral host and can support multiple overlapping operator networks in the same area, and 5G radios will depend on carrier aggregation of unlicensed spectrum. It is increasingly common in public venues to see overlapping operator Wi-Fi networks, and now LAA networks, operating in 5 GHz.[44] A sufficient multiple of unlicensed spectrum compared to the amount of licensed spectrum must be available to support these networks, especially considering the amount of mobile traffic offloaded onto Wi-Fi. Unlicensed technologies that operate on an uncoordinated or self-coordinating basis, such as Wi-Fi, require at least nine channels (regardless of bandwidth) to operate well and balance loads.

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43 *See, e.g., Use of Spectrum Bands Above 24 GHz for Mobile Radio Services*, Report and Order and Further Notice of Proposed Rulemaking, FCC No. 16-89, GN Docket No. 14-177 at ¶ 130 (rel. July 14, 2016) (permitting the use of 57-71 GHz for unlicensed use and noting that "a strict linear comparison per frequency unit of spectrum amount in different frequency bands as 'gigahertz parity'… is not a valid comparison").

44 *See, e.g.*, AT&T, *Path to 5G* (last accessed: Mar. 17, 2019), https://about.att.com/ecms/dam/snr/2018/October2018/InStory/5G-Map-100518.jpg, (showing markets where LTE-LAA service has been deployed throughout the United States).

II. THE COMMISSION SHOULD REJECT QUALCOMM'S REQUEST TO FAVOR ONE CLASS OF UNLICENSED DEVICES OVER ALL OTHERS IN THE U-NII-7 BAND.

The Commission should adopt its proposal to open the U-NII-7 band to all types of unlicensed technologies and reject Qualcomm's request to set aside spectrum in U-NII-7 for synchronization-capable unlicensed systems such as 5G NR-U.[45] While HPE agrees with many aspects of Qualcomm's filing, its argument that such a U-NII-7 set aside rule would be technologically neutral is patently self-contradictory and would effectively convert an unlicensed band intended for general use into a reserved band for products based on Qualcomm's intellectual property (without even conducting an auction). Far from being technologically neutral, the stated purpose of its proposal is to advantage one specific type of unlicensed technology over all others. The FCC has never adopted rules favoring one class of unlicensed device over others and it should not do so here.

Qualcomm's proposal is not technology neutral because it would block all unlicensed devices from operating in U-NII-7 unless they detect an over-the-air synchronization timing reference. Although Qualcomm claims this proposal is technologically neutral, it is not. Qualcomm states that, "[t]o be clear, we are requesting that the Commission implement a rule requiring each access node operating in the U-NII-7 portion of the 6 GHz band to listen for synchronized nodes, and, if the node detects synchronized operations, it would contend in a synchronized manner by utilizing over the air signaling from the synchronized nodes."[46] Qualcomm is clear that this creates a priority system: "it gives precedence to synchronized operations in this portion of band but allows non-

[45] Qualcomm Comments at 18-23.

[46] Qualcomm Comments at 23.

synchronized operations when no over the air synchronization timing reference signaling is detected."[47]

Qualcomm does not contend with the fact their proposal would exclude the Wi-Fi that consumers use today. Instead, it implies that there could be a new synchronized version of 802.11be (EHT) that could qualify. But this is exceptionally unlikely. One of the fundamental, defining features of Wi-Fi is that it can be deployed by anyone, anytime, anywhere, for any reason without any a priori permission (so long as devices pass FCC certification). Imposing a synchronization requirement therefore would essentially foreclose Wi-Fi deployment in U-NII-7. Even if the hypothetical synchronized Wi-Fi became a reality (likely using Qualcomm's patents), it could never be deployed because Wi-Fi system operators are unknown to one another, may be transitory, and no interconnection method exists to broker agreements between them for airtime allocation. Indeed, the synchronization proposal raises a host of thorny and intractable problems: How would synchronous detection work? What about hidden nodes? Who will operate the master scheduler for a given domain? Who will decide how airtime or capacity is allocated? Who will operate the inevitably-required control channel? What does it cost to license the intellectual property of the relevant technology?

Additionally, Qualcomm's argument that synchronized systems are necessarily more efficient than Wi-Fi is incorrect. Wi-Fi is an excellent steward of any band it occupies from a spectral efficiency perspective. HPE's analysis has revealed that, at the physical layer, Wi-Fi has an almost identical value of symbols-per-second-per-Hertz-per stream as LTE, with spectral efficiency depending on the number of bits per symbol, determined at the QAM level by chip technology. This is shown in Figure 1 below. After normalizing for bandwidth, symbol duration, and usable

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[47] *Id.*

subcarrier count for a single spatial stream, LTE Release 12 has very a similar symbol rate to 802.11ac (16.8 Msymbols/sec vs. 16.3 Msymbols/sec), and a significantly lower symbol rate than the new 802.11ax standard (18.0 Msymbols/sec).

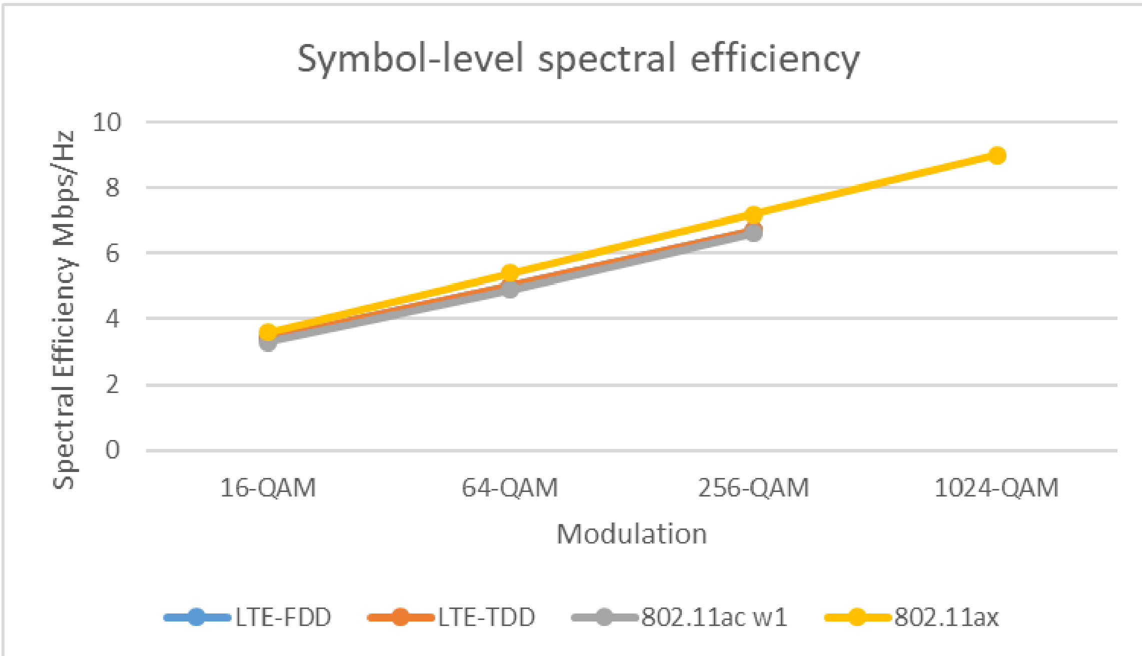

Figure 1 – Spectral efficiency comparison of LTE Release 12, 802.11ac, and 802.11ax physical layer

These similarities extend to the medium access control ("MAC") layer. The LTE air interface requires significant overhead of its own to provide synchronization and control signaling to user equipment within a cell. A normalized comparison of LTE-TDD, LTE-FDD and 802.11 in a 20 MHz channel reveals that both systems have very comparable MAC layer spectral efficiencies. For example, in a cell with one station (or UE) that is passing bidirectional full-buffer traffic, the total MAC layer LTE-FDD overhead amounts to over 15% of the available physical resource elements ("PREs") in the downlink direction and nearly 17% in the uplink direction, as compared with just over 15% airtime for 802.11.[48] When these overheads are considered in terms of net spectral efficiency, as one might expect, the FDD mode of LTE is somewhat more efficient, but only by 15%. LTE-TDD mode, on the other hand, has a 10% disadvantage to 802.11ac at 256QAM. It should be noted that Wi-Fi overhead scales with offered load, whereas LTE overhead is essentially fixed regardless of load due to the rigid framing structure it employs. A Wi-Fi cell with a single idle user consumes well under 1%, whereas an eNodeB with one attached UE still produces nearly constant duty cycle on a significant number of subcarriers.

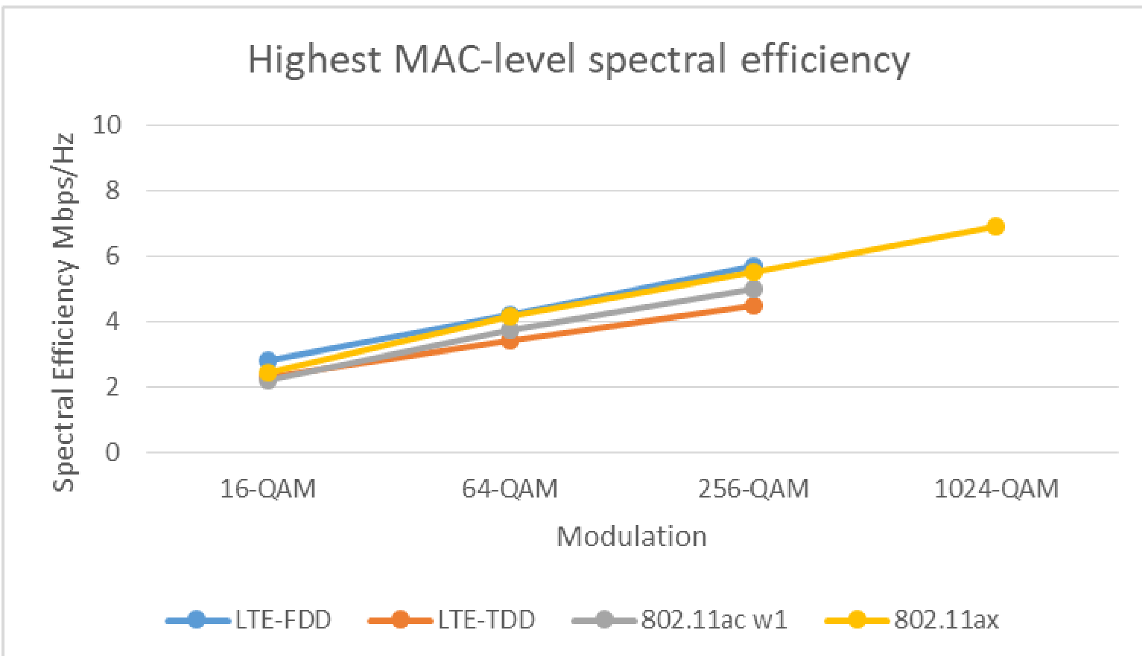

Figure 2 – Spectral efficiency comparison of LTE Release 12, 802.11ac, and 802.11ax MAC layer with full-buffer bidirectional traffic

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48 LTE-FDD downlink overhead consists of 24,000 PREs/frame for a 4TX eNodeB + 240 PREs/frame for PBCH + 288 PREs/frame for SCH + 800 PREs/frame for PCFICH+CFI+ PHICH+HARQ+PDCCH+DCI = 25,328 PREs/frame. There are a total of 168,000 PREs/frame before subtracting overhead. 25,328/168,000=15.07%. LTE-FDD uplink consumes 28,368 PREs/frame for PUSCH+PUCCH+PRACH. By contrast, 802.11 MAC layer overhead consists of EDCA quiet time for contention+RTS+CTS+preambles+MAC headers+MPDU delimeters+SIFS+Block Ack+NDP+Beacons = 15.02% airtime in a full buffer BSS.

This analysis makes clear that 802.11 and cellular radio technology have extremely similar performance in conditions that would be expected from the small cells contemplated by Qualcomm's proposal. This makes intuitive sense when one considers that both LTE and 802.11 are based on OFDM, as will be 5G NR. Both systems make effective use of shared spectrum. To the extent that incremental improvements are possible through better coordination, the public interest weighs in favor of the Commission refraining from command-and-control regulation and instead allowing the marketplace to pick the best technology. HPE is confident that the result will be that the more democratic, user-neutral, self-coordinating technology will prevail over a proprietary technology reserved for only certain companies.

In the end, the result of Qualcomm's proposal would not be more efficiency. It would be to reserve U-NII-7 for Qualcomm's next generation LTE-LAA, 5G NR-U and MulteFire products so they have less competition from Wi-Fi devices. Not only would this be an inappropriate use of FCC regulation, but it would drastically limit the utility of the entire 6 GHz band. As a practical matter, this proposal would eliminate five 80 MHz channels and three 160 MHz channels from the spectrum pool available to Wi-Fi systems in 6 GHz when synchronized systems are detected nearby. Those channels would have to be treated differently by radio resource management ("RRM") systems such as Aruba's AirMatch service because client devices roaming through a building could not expect the same type of user experience on these channels.

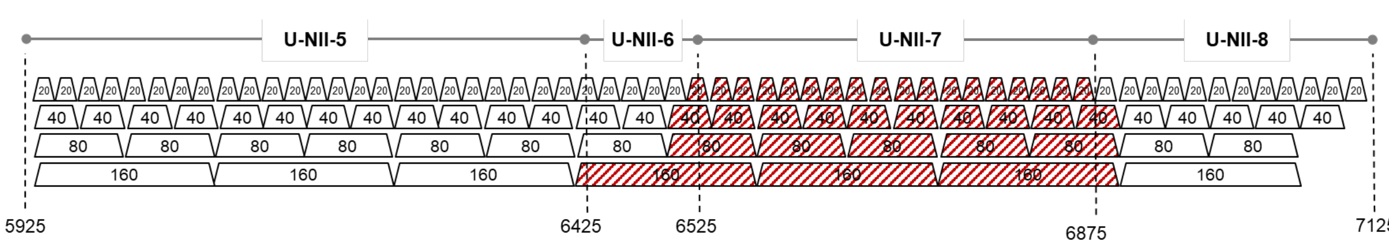

Figure 3 – Effect of Qualcomm proposal on channel availability in other U-NII subbands

While any consumer or business can use a Wi-Fi device for broadband access, the cumulative effect of this proposal would be that only a handful of companies with licensed spectrum on which to place control channels can use LTE-LAA. And even if Qualcomm's MulteFire or NR-U Standalone products become commercially available sometime in the future, consumers would still remain beholden to Qualcomm for this technology, rather than have the freedom that Wi-Fi offers. Certainly, this is not an appropriate use of FCC rules.

The FCC has never used government power to dictate which specific technology should have access to an unlicensed band, thereby replacing market forces with its judgment. The hallmark of the Commission's successful unlicensed rules is flexibility and the ability to innovate. The Commission should continue that tradition in the 6 GHz band by adopting rules that allow many different unlicensed technologies to thrive and coexist. Qualcomm does not need the Commission to protect and favor its new technology for the 6 GHz band. It has successfully developed technologies including an NR-U standalone for the 6 GHz band and an upgraded version of MulteFire.[49] If a fully synchronized, fully coordinated technology is truly superior, the market will eventually make that determination and market participants will adjust accordingly.

III. RECORD EVIDENCE THAT UNLICENSED OPERATIONS WILL PROTECT INCUMBENTS FROM HARMFUL INTERFERENCE IS BASED ON CONSERVATIVE AND WELL-FOUNDED PARAMETERS.

The record in this proceeding contains detailed technical analysis from HPE and other commenters with significant experience in operating and using unlicensed RLAN systems. This analysis shows that the Commission can authorize unlicensed devices to operate throughout the

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[49] *See* Press Release, Qualcomm Technologies, Inc., *Qualcomm Showcases 5G NR Technology Evolution with New Applications and Expanded Use Cases at Mobile World Congress 2019* (Feb. 19, 2019), https://www.qualcomm.com/news/releases/2019/02/19/qualcomm-showcases-5g-nr-technology-evolution-new-applications-and-expanded; Monica Alleven, *MulteFire Alliance completes new specification optimized for IoT*, FierceWireless (Dec. 4, 2018), https://www.fiercewireless.com/wireless/multefire-alliance-completes-new-spec-optimized-for-iot.

6 GHz band without risking harmful interference to licensed incumbents.[50] But rather than offer detailed studies of their own, some commenters merely question the inputs and assumptions contained in RLAN interference studies.[51] As described in this section, however, engineering analyses in the record demonstrate that RLANs will not cause harmful interference to licensees, even using the conservative parameters that underlay the RKF study.

A. The record substantiates very-low RLAN duty cycles due to the modern protocols used by RLAN devices.

Specifically, some commenters misinterpreted the established record relating to RLAN duty cycles.[52] RKF aggregated the combined data consumption of every person in the U.S. streaming HD video simultaneously, in addition to constant lower-intensity utilization by another nine devices per person.[53] The study assumed an average per capita data consumption of 750 GB per month for RLAN devices alone, which is over 250 GB more than the 2025 estimate of 492 GB per month

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[50] *See, e.g.*, RKF Engineering Solutions, Coexistence Study for Radio Local Area Networks in the 6 GHz Band in the Continental United States (Jan. 25, 2018) *in* Letter from Paul Margie to Marlene Dortch, GN Docket No. 17-183 (filed Jan. 26, 2018) ("RKF Study"); RLAN Group Comments at Appendix A, Declaration of Dr. Vinko Erceg; HPE Comments at Attachment 1, Duty Cycle Analysis; Letter from Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183 (filed June 12, 2018); Letter from Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Marvell Technology Group, Microsoft Corporation, and Qualcomm Incorporated to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183 (filed Aug. 16, 2018); Letter from Paul Margie, Counsel to Apple Inc., Broadcom Inc., Facebook, Inc., Hewlett Packard Enterprise and Microsoft Corporation to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183 (filed Apr. 12, 2018).

[51] *See e.g.*, FWCC Comments at 3-4; Comments of Texas New Mexico Power Company at 1 (filed Jan. 17, 2019).

[52] *See, e.g.*, Nokia Comments at Technical Appendix, 5-6 (assuming a "full buffer" for U-NII traffic model).

[53] RKF Study at 15.

extrapolated from Cisco's recent VNI data.[54] These are extremely conservative assumptions. By contrast, Nokia's "full buffer" (i.e. 100% duty cycle) assumption is unrealistic. It would require an assumption that users download 450 GB per hour, equivalent to streaming hundreds of HD movies. This is clearly not the case. Similarly, Globalstar's smaller, but still incorrect assumption of a 10% duty cycle would require an assumption that every user downloads an amount equivalent to 45 GB *per hour*, which is also clearly not the case.[55]

In considering the duty-cycle issue, it is important to recognize that although a Wi-Fi device may appear to be continuously transmitting from a user's perspective, the radio link activity is mostly inactive. Individual RLAN devices using modern protocols are silent far more frequently than they are transmitting, even under heavy traffic loads. This "burst" transmission behavior balances individual users' performance needs with the objective of achieving maximum aggregate throughput for numerous devices sharing a channel.

B. RKF's technical study regarding RLAN co-existence is based on conservative inputs.

Contrary to the arguments made by some commenters, the RKF Study did not simply rely on average probabilities of interference, and certainly not on an average of averages aggregated over

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[54] *See id.*; Cisco, *VNI Forecast Highlights Tool*, https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html (last visited Mar. 11, 2019) (extrapolating from Cisco's 2022 forecast of 289.4 GB/month and assuming a 20% year-over-year growth in data consumption). *See also* Letter from Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company to Marlene H. Dortch, Secretary, Federal Communications Commission, Docket No. 17-183, at 3-4 (filed May 14, 2018) ("FS Response").

[55] *See* Comments of Globalstar, Inc. at Technical Analysis of Impact of Unlicensed Operations in U-NII-8 on Globalstar Mobile Satellite Service at 22 (2018) (assuming a 10% activity factor).

many runs.[56] The Monte Carlo analysis underlying the RKF Study studied distributions of probabilities of different situation parameters and used very large numbers of simulation runs to account for the probability and magnitude of all scenarios, including worst-case scenarios. For example, the RKF Study singled out certain links where RLAN devices exceeded the specified interference threshold and performed an additional 1,000 simulations to arrive at an I/N distribution, which RKF used to calculate the figure for the increase in link unavailability.[57] In response, FWCC contends that *no* statistical modeling approach would ever be adequate for predicting interference.[58] But the Commission's Technological Advisory Council disagrees, regularly conducting and preparing such statistical analyses for the Commission's consideration when adopting new rules or implementing spectrum coexistence strategies.[59]

Commenters also misunderstand the conservative, and even over-inclusive, assumptions underlying the RKF Study. For example, NAB contends that the statistical simulation RKF used to model interference to electronic newsgathering links is flawed because the locations of such links are not random.[60] However, the RKF Study recognized this very issue and accounted for it. The study explains that, to account for the random selection of the mobile transmitter sites, RKF "first calculated the link margin *without* RLAN interference. In cases where the link margin was insufficient

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56 FWCC Comments at 3-4, 11; NAB Comments at 5-6.

57 RKF Study at 51.

58 *See* FWCC Comments at 4, 10-11.

59 *See, e.g.*, Satellite Communication Plan Working Group, FCC Technological Advisory Council, *A Risk Assessment Framework for NGSO-NGSO Interference* (Dec. 6, 2017), https://transition.fcc.gov/oet/tac/tacdocs/meeting12617/TAC-NGSO-risk-assessment-framework-v100-2017-12-06.pdf.

60 *See* NAB Comments at 6 (contending that ENG locations are not randomly sited because crews dispatch the trucks to locations where they know the link will function properly, and, in any location, the crews adjust the trucks to close the link.).

to close the link, [RKF] discarded that location and selected another. The simulation was repeated until 10,000 MS locations with closed links (in the absence of RLANs) were generated. The simulation containing the 10,000 MS locations was then run in the presence of RLANs."[61]

The Commission can therefore be confident in relying on the well-informed and well-explained engineering models, predictions, and data in the record in adopting new rules for the 6 GHz band. This includes the Commission's own analysis in the NPRM and the explanations recently provided by commenters in response to the NPRM. For example, as explained in its comments, HPE encourages the Commission to give serious consideration to the interference protection criteria of 0 dB I/N for AFC calculations shown in the NPRM, which is also supported by the Wireless Internet Service Providers Association.[62] Additionally, HPE highlights the discussion and engineering declaration in the RLAN Group Comments explaining that a combination of the WINNER II and Irregular Terrain Models (plus the Shuttle Radar Topography Model when available), combined with applicable ITU clutter models, are the best propagation models for the AFC to use.[63]

IV. BASED ON THESE STUDIES, THE COMMISSION SHOULD ADOPT ITS PROPOSED FRAMEWORK, ALLOWING UNLICENSED USE TO FLOURISH WHILE PROTECTING INCUMBENTS.

As noted above, HPE supports the overall framework the Commission has proposed for allowing unlicensed use in the 6 GHz band, as do numerous other commenters. HPE urges the Commission to adopt this framework and implement the rules governing the AFC, different device

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[61] RKF Study at 56-57 (emphasis in original).

[62] WISPA Comments at 20. *See* NPRM at ¶ 43; HPE Comments at 27-28.

[63] RLAN Group Comments at 43-45, Appendix A, Declaration of Dr. Vinko Erceg.

classes, and technical parameters as explained below and in HPE's comments in this proceeding. Doing so will both ensure interference protection and promote investment in unlicensed operations.

A. ULS accuracy and re-check.

Most commenters addressing the topic agree that ULS is technically capable of performing the license database function for the AFC and that the AFC should periodically check for updated license information.[64] To the extent there is disagreement, it is over the accuracy of incumbent ULS submissions.[65] The Commission therefore should use the AFC development period to simultaneously require incumbents to update their information so they come into compliance with FCC rules.[66]

There is no reason to wait. As part of its initial Report and Order, the Commission should (i) mandate that all incumbents operating in the band update all ULS fields, and (ii) provide a one-year moratorium on filing fees and an amnesty on re-coordination requirements for links operating for at least one year.[67] It will take a minimum of one year to design, build, test and certify the AFC systems. Those tests will perform better with accurate information. To speed time to market for consumers, the Commission should address any concerns about ULS readiness sooner rather than later. Furthermore, the Commission should adopt a reasonable interval for RLAN re-checks of the database. A re-check every 24 hours as suggested by some commenters is not necessary because

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[64] *See* APCO Comments at 10-11; DSA Comments at 10, 12; El Paso Electric Comments at 4; NSMA Comments at 4; Qualcomm Comments at 11; RLAN Group Comments at 41-42; Sony Comments at 4-5; Wi-Fi Alliance Comments at 21-23.

[65] *See* Critical Infrastructure Coalition Comments at 15; NSMA Comments at 4; Sony Comments at 4-5; Tucson Electric Power Comments at 15 n.38; Xcel Comments at 5.

[66] *See* DSA Reply Comments at 8-9.

[67] *See* 47 U.S.C. § 159a(d) ("The Commission may waive, reduce, or defer payment of a fee under section 158 [for applications] . . . in any specific instance for good cause shown, where such action would promote the public interest.").

ULS operations do not change that quickly and because new sites enter ULS far ahead of activation.[68] A 30-day re-check interval for stationary APs is sufficient.[69] ULS data reveals that, in almost all scenarios, the application for a new FS link is posted to ULS at least 30 days before the link enters into operation.[70] Thus, where an FS operator posts a new application in ULS directly after an AFC re-checks the database, the AFC will still perform an additional re-check before the link becomes operational, even if the gap between FS application and operation is an extremely short 30-day period, as illustrated by Figure 4 below.

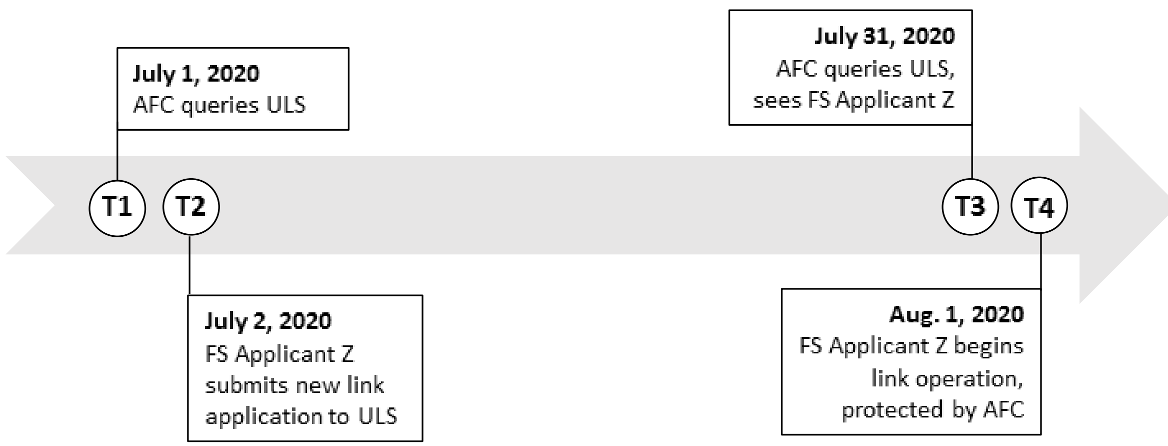

Figure 4 – A 30-day re-check interval protects new FS links

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68 APCO Comments at 7; NYC Comments at 4.

69 DSA Comments at 10 ("[A] one-month recheck interval is more than sufficient."); RLAN Group Comments at 42 ("AFC will protect FS links as long as AFC implementations obtain up-to-date information at least once every 30 days."); Wi-Fi Alliance at 23 ("It . . . should be sufficient for the standard-power AP to verify available channel assignments with the AFC every 30 days.").

70 *See* RLAN Group Comments, Appendix C, Declaration of Fred Goldstein Regarding AFC Operation and ULS Database at C-3-C-5.

B. Flexibility in AFC implementation and standards setting.

The Commission should additionally allow for decentralized AFC implementations and should not require device registration or identifiers. The record provides strong support for the Commission's proposal to designate multiple AFC operators.[71] Each operator can function in a decentralized manner because of the relative simplicity of the AFC compared to databases such as the SAS.[72] Importantly, the Commission should not require device registration or transmit identifiers for APs because an identifier for each AP is not necessary for harmful interference protection under the Commission's proposed framework—and would in fact create unacceptable user privacy risks as it could allow for location monitoring of users.[73] Imposing a device registration and identifier requirement would create the unacceptable risk that "[m]alicious actors could surreptitiously monitor 6 GHz identifier transmissions on a large scale, gathering sensitive data about where an individual consumer is at a particular time."[74] The FWCC argues that, in any event, transmission of digital identifiers for individual RLAN devices would be unhelpful because, as the Commission notes in its NPRM, FS operators do not know about any interference until after the link fails and FS

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[71] *See* NPRM at ¶ 33; APCO Comments at 10; Apple Comments at 11-13; Broadcom Comments at 43-44; Comsearch Comments at 25-6; DSA Comments at 12; Facebook Comments at 9; Federated Wireless Comments at 11-12; Microsoft Comments at 20; Motorola Comments at 4-5; Comments of NETGEAR, Inc. at 2 (filed Feb. 13, 2019); PIO Comments at 26; Quantenna Comments at 5; Sony Comments at 7-8; Teradek/Amimon Comments at 6; Wi Fi Alliance Comments at 26-27; WISPA Comments at 19-20.

[72] *See* NPRM at ¶ 62 & n.143 (noting that "the RKF Technical Study showed that the aggregate interference risk from unlicensed devices to fixed service receivers is not substantially different from the single-entry interference risk"); Facebook Comments at 9-10 ("There is no need for aggregate interference protection or any other need for data to be synchronized between operators.").

[73] *See* Apple Comments at 14-16.

[74] RLAN Group Comments at 65.

receivers have no ability to decode the digital ID.[75] Instead, the Commission can and should adopt a "result-oriented and flexible framework" in the 6 GHz band that allows for competing AFC approaches as long as the Commission can certify that the AFC correctly and reliably performs its interference protection function.[76]

Furthermore, the Commission should encourage more than one multi-stakeholder body to develop AFC standards. Wi-Fi and unlicensed LTE or NR-U technologies will employ different radio technologies and may employ different channelizations over time. And each likely requires a different multi-stakeholder body—for example, IEEE or Wi-Fi Alliance on the one hand, and 3GPP or WinnForum on the other—to develop technical standards to govern AFC operation for devices using their particular technology and channelization.

The Commission should not designate a single multi-stakeholder body to develop these standards. First, doing so is unnecessary. The FCC should set the outcomes the AFC must accomplish and permit each AFC the flexibility to engineer solutions. This will ensure that AFCs can innovate, make changes as technologies advance, and customize operations to particular technologies or use cases. Having a single standard AFC is not needed because, as discussed above, in the 6 GHz band, AFCs do not need to interoperate. Second, doing so would be counterproductive and could undermine competition. Choosing, for example, either Wi-Fi Alliance or WinnForum to develop AFC standards for both Wi-Fi and LTE devices would, at best, risk forcing an entire technology class to abide by standards that are inappropriate to their devices and channelization and security techniques. At worst, it would subject one technology class or the other to governance by a multi-stakeholder body where it is not represented or lacks the ability to ensure

75 *See* FWCC Comments at 34; NPRM at ¶ 87.

76 PIO Comments at 26.

standards address their concerns, and have to spend substantial financial resources to attend meetings of a new organization. For example, only 24 of WinnForum's 89 members are common to both organizations, and they have only two board member companies in common.[77]

C. Permitting low-power-indoor, very-low-power, and portable devices.

The record also reflects that the Commission should authorize operations in the 6 GHz band that will permit efficient use of the spectrum though a variety of deployment scenarios, including: (1) low-power indoor ("LPI") operations throughout the band; (2) very-low-power operations at 14 dBm indoors throughout the band and outdoors in U-NII-5, -7, and part of -8; and (3) portable standard-power operations under AFC control. In addition to HPE, numerous parties support the Commission's proposal to allow LPI operations throughout the entire 6 GHz band.[78] As HPE and others have explained, LPI operations will be critical to the commercial success of the band, and the Commission should adopt rules to permit its widespread use.[79] Several commenters additionally explain that the Commission can authorize an additional very-low-power ("VLP") device class to operate at 14 dBm indoors throughout the band and outdoors without AFC control in U-NII-5, -7, and part of -8.[80] Very-low-power devices would operate in geometries and at

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[77] Comparison of Wireless Innovation Forum, *Current Members* (last accessed: Mar. 17, 2019), https://www.wirelessinnovation.org/current_members and Wi-Fi Alliance, *Membership* (last accessed: Mar. 17, 2019), https://www.wi-fi.org/membership conducted on March 15, 2019.

[78] *See* NPRM at ¶ 73; Apple Comments at 3; Boeing Comments at 6-7; Broadcom Comments at 5-16; Comments of Cambium Networks at 2; Charter Comments at 3; Cisco Comments at 10-13; CompTIA Comments at 2; Facebook Comments at 3-4; GEHC Comments at 7-8; Comments of HP Inc. at 3-4; Microsoft Comments at 5-11; NCTA Comments at 15-16; NETGEAR Comments at 2-3; Qualcomm Comments at 9-10; Quantenna Comments at 3-4; PIO Comments at 17-20; Wi Fi Alliance Comments at 10-17; WISPA Comments at 27-28.

[79] Cisco Comments at 13, Microsoft Comments at 2-5.

[80] Apple Comments at 2-3, 7-9; Broadcom Comments at 27-31; Facebook Comments at 5-6; RLAN Group Comments at 16-17.

sufficiently low power levels and power spectral density levels in particular as to pose no real-world risk of harmful interference to licensed services.[81] Finally, commenters explain that AFC control or very-low-power operation will ensure that transportable APs do not cause harmful interference,[82] and that the attenuation from vehicles—aircraft in particular—will additionally protect licensees from harmful interference.[83] HPE therefore encourages the Commission to permit LPI, VLP, and portable devices.

D. RLAN control signals.

Control signals similarly allow unlicensed networks to self-coordinate—they provide a way for client devices to know whether they can associate or re-associate with an access point. The record supports HPE's argument that the Commission should permit client devices to send extremely brief signals to allow client devices to join or rejoin networks rapidly and prevent service disruptions.[84] Commenters explain that the Commission should permit client devices to transmit such probe requests, from which the probability of interference is negligible.[85] HPE's comments provide technical analysis explaining that such transmissions involve a de minimis duty cycle.[86]

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81 *See* Broadcom Comments at 29.

82 Apple Comments at 4-10; Broadcom Comments at 27-31, 45-46; DSA Comments at 14-15; HPE Comments at 25-26; NETGEAR Comments at 3; Qualcomm Comments at 15-16; RLAN Group Comments at 50-53; Sony Comments at 9; Teradek/Amimon Comments at 8; UWB Comments at 9; Wi-Fi Alliance Comments at 34-35.

83 *See* Apple Comments at 7-11; Boeing Comments at 7-11; RLAN Group Comments at 53.

84 HPE Comments at 30.

85 Wi-Fi Alliance Comments at 28; *see also* Teradek/Amimon Comments at 9; NPRM at ¶ 53.

86 HPE Comments at 30, Appendix 1: Duty Cycle Analysis of Wi-Fi Client Network Discovery Probe Requests in Two Primary Deployment Scenarios.

E. Point-to-point and point-to-multipoint systems.

Additionally, the Commission should permit point-to-point and modern steerable beam point-to-multipoint systems in the band by enabling higher gain antennas and antennas with directional gain, as supported by several commenters, including HPE.[87] AFC systems can manage these antennas like any other antenna pattern: "the AFC is capable of determining protection contours irrespective of whether the unlicensed operations are point-to-point or point-to-multipoint."[88] In addition to supporting enterprise customers, special events and venues, and managed use cases,[89] rules allowing unlicensed point-to-point and point-to-multipoint operations would allow wireless internet service providers to provide lower-cost broadband access in rural and underserved areas.[90]

F. Two-dimensional and three-dimensional protection contours.

Three-dimensional protection contours—those that account for RLAN height as well as x- and y-coordinates—will allow for more effective deployment in a diversity of locations and scenarios without sacrificing the interference protection function performed by an AFC. Numerous commenters support the Commission's proposal to allow the AFC to account for height in its calculations.[91] Commenters explain that accounting for vertical as well as horizontal location will

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87 *See* Facebook Comments at 8-9; HPE Comments at 29-30; Comments of Midcontinent Communications at 10-11 ("Midcontinent Comments"); Starry Comments at 2-3; WISPA Comments at 10-11. *See also* NPRM at ¶ 79 (asking whether point-to-multipoint operations should be permitted).

88 WISPA Comments at 10.

89 HPE Comments at 29.

90 WISPA Comments at 9-11, Facebook Comments at 7-9.

91 *See* NPRM at ¶¶ 51-52; APCO Comments at 14; DSA Comments at 13; Comsearch Comments at Attachment A, tbl.3; FWCC Comments at 13, 29-30; Microsoft Comments at 19; Motorola Comments at 4; NCTA Comments at 12-13; NPSTC Comments at 11; NSMA Comments at 24;

lead to more accurate interference prediction calculations and will "greatly improve the accuracy of the modeling performed in the AFC function."[92] If the AFC is permitted to account for device height, there is no need to limit AP deployment height or create a less accurate, two-dimensional protection contour using typical AP installation heights.[93] At least one commenter notes that imposing a height limit on APs in U-NII-5 and -7 could have the undesirable effect of limiting providers' abilities to serve rural areas.[94]

HPE agrees with the commenters who have argued for the use of actual antenna patterns by the AFC to calculate three-dimensional protection contours for both the FS receiver and the RLAN service area.[95] HPE can corroborate Broadcom's comments regarding negative average EIRP for typical Wi-Fi enterprise access points.[96] Consider our new, state-of-the-art AP-345 802.11ac Wave 2 access point with 4x4 MIMO. We took pattern measurements of each element in our anechoic chamber at every five degrees for theta and phi, resulting in 2,592 measurements in three dimensions. The peak gains of each element were 5.76 dBi, 3.83 dBi, 4.08 dBi and 3.12 dBi. These peak gains were down-tilted at approximately 30 degrees from horizontal, consistent with the antenna patterns shown in the joint Enterprise Networking Declaration attached to the RLAN

NYC Comments at 3; Sony Comments at 1; Comments of Southern Company Services, Inc. at 17; Starry Comments at 4; Wi-Fi Alliance Comments at 26; WISPA Comments at 17-18.

92 Motorola Comments at 4.

93 *See* NPRM at ¶ 51.

94 Midcontinent Comments at 3-6.

95 *See* Broadcom Comments at 12-14; Motorola Comments at 4; NPRM at ¶ 37 (proposing that "unlicensed devices need only be excluded from a zone determined by the fixed service receive antenna pattern and the EIRP of the unlicensed device").

96 *See* Broadcom Comments at 13.

Group Comments.[97] However, linear averaging of the gain across all 2,592 measurements yields a peak average gain of just 2.64 dBi, and the *average gain of the combined pattern of -3.70 dBi*. This is consistent with Broadcom's findings for a popular consumer AP.[98]

V. RLAN Operations, Including Very-Low-Power APs, Can Co-Exist With Ultra-Wideband Operations Using Situation-Specific Coordination Where Appropriate.

The Commission correctly proposes not to make changes to the existing Part 15 provisions governing the use of unlicensed ultra-wideband ("UWB") systems in the 6 GHz band. It is correct to expect that such systems "will continue to coexist with all other systems, both licensed and unlicensed, within the 6 GHz band."[99] UWB technology operates under the Part 15 Rules that provide no protection against unintentional interference.[100] Indeed, new unlicensed users of the 6 GHz band would operate under the same expectations and will make investments and plan technology development accordingly. The Commission should reject calls to adopt rules for significantly restricted power limits and operating constraints that favor certain existing types of unlicensed technology over others.[101]

Instead, the Commission should recognize that the best strategy for maximizing the potential of the 6 GHz band and facilitating coexistence between these two unlicensed technologies is frequency coordination by venue, in the rare instances where it is needed. Given the short range

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97 *See* RLAN Group Comments, Appendix D, Characteristics of Enterprise Deployments Using IEEE 802.11 Equipment: Joint Declaration of Matt McPherson, Chuck Lukaszewski, and Sundar Sankaran at D-6.

98 *See* Broadcom Comments at 13 (explaining that measurements from one of its four-antenna AP systems showed an average gain, over 7260 measured angles, of -2.11 dBi).

99 NPRM at ¶ 72.

100 *See* Wi-Fi Alliance Comments at 39.

101 *See* Comments of Zebra Technologies, Inc. at 4-6.

of UWB devices, much of the interference potential between RLANs and UWB systems will occur in the uncommon, discrete, and privately controlled locations that use UWB devices.[102] Instead of limiting the capabilities of RLAN devices throughout the band and across the board because of these particular locations, the Commission should expect that operators will undertake coordination and mitigation for specific locations through the use of shielding mechanisms or frequency management using AP settings to avoid the potential for harmful interference. In any event, the introduction of new unlicensed technologies at the (already conservative) power levels proposed in the NPRM is unlikely to preclude the use of lower-power UWB operations in the 6 GHz band any more than in the 2.4 and 5 GHz bands, where RLAN operations have long been authorized and where applications such as RFID, ZigBee, and others are successfully deployed.

While not intended specifically for UWB coexistence, HPE notes that the RLAN Group proposals regarding the very-low-power device class are responsive to the concerns of UWB interests. A venue or private enterprise such as a large manufacturer, as cited by Zebra, that employs frequency coordination to segregate RLAN and UWB systems would manage the placement of fixed RLANs, and therefore only see potential interference from mobile APs. The RLAN Group proposal of 14 dBm EIRP with 1 dBm/MHz PSD for VLP devices, in conjunction with venue frequency coordination, should be highly effective at promoting coexistence.

Finally, HPE notes that all Part 15 devices are required to accept harmful interference, and by definition there can be no assurance of perfect coexistence. But the Commission should reject proposals by UWB interests for duty cycle constraints, EIRP limits, beacon "fences," and deployment limitations which are inherently unworkable and inconsistent with FCC unlicensed-band

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[102] *See* Wi-Fi Alliance Comments at 39.

policies. Boeing's reasonable reaction is the right model. It acknowledged its own UWB operations, but declined to endorse the extreme measures offered by other UWB interests, and went on to advocate for RLAN use across the band.[103] On the other hand, HPE understands the observation by some UWB interests that current Commission rules effectively allow only a single channel with 0 dBm peak power, as compared with other major regulatory domains that permit such operation up to 8.5 GHz. Given our deep experience in stadiums, we appreciate the need for the Zebra player tracking solution to operate outdoors and at higher peak power. HPE would support a separate proceeding to consider extending the Commission's UWB rules under 47 C.F.R. § 15.250 to include additional spectrum, which may be timely considering the calls on NTIA to evaluate sharing opportunities above 7.125 GHz.

VI. CONCLUSION

The Commission possesses a remarkably well-developed record in this proceeding and can use it to confidently adopt rules that allow RLAN operations across the band, addressing the nation's need for more unlicensed frequencies. To adopt a set of rules that will protect incumbent licensees while maximizing the band's utility, the Commission should:

- Reject CTIA's and Ericsson's unworkable proposals to forcibly displace incumbents in favor of new mobile licensed services in the band;
- Adopt technology-neutral unlicensed rules and reject Qualcomm's proposal to establish rules that prioritize one unlicensed technology above all others;
- Rely on well-supported technical and engineering analysis in the record, including the RKF study, to adopt rules that permit standard-power, low-power-indoor, very-low-power, and portable RLANs; and
- Adopt technical issues that robustly protect incumbents, but do not overregulate.

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[103] *See* Boeing Comments at 5-7, 12.

HPE thanks the Commission for its continued hard work. We are already working hard to prepare to build and ship products that will make the 6 GHz band a success.

Respectfully submitted,

Chuck Lukaszewski
Vice President, Wireless Strategy
Hewlett Packard Enterprise
3333 Scott Boulevard
Santa Clara, CA 95054

March 18, 2019

Appendix A

Quotient Associates

Wi-Fi Spectrum Needs Study

Final Report

Final Report to Wi-Fi Alliance, February 2017

www.QuotientAssociates.com

Contributors

Steve Methley
William Webb

Quotient Associates Limited
Compass House, Vision Park, Chivers Way,
Histon, Cambridge, CB24 9AD, UK
EMAIL Enquiries@QuotientAssociates.com
WEB www.QuotientAssociates.com

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Contents

0 EXECUTIVE SUMMARY

This report describes our predictions of the spectrum required in future, in order to satisfy the growth in the expected demand for Wi-Fi services.

Methodology

We sought evidence based traffic predictions from several perspectives. We included a Busy Hour growth scenario and an Upper Bound scenario, both with consideration of internal traffic such as in-band backhaul where appropriate. We considered location types of office, residential and mall.

In terms of use cases, we considered the shift in emphasis with respect to the most important devices used to connect to the internet. We looked at how device capabilities were expected to develop per device type over time and the distribution of device types per location type. The key performance metric we used in our airtime based modelling was Wi-Fi network utilisation. The target was 70% utilisation at the 95th percentile.

Key results

We have shown that, for the year 2025, the various regions are likely to need to find between 500 MHz and 1 GHz more spectrum than currently available to satisfy the Busy Hour scenario, which reflects the widely expected growth in traffic. If demand were to exceed the present Busy Hour predictions, our Upper Bound scenario suggests that an estimated maximum of between 1.3 and 1.8 GHz more spectrum than currently available may be needed. The Upper Bound scenario might occur due to unexpected adoption of novel applications or a further concentration of the busy hour traffic into fewer than the assumed four hours per day, for example. In other words, the Busy Hour scenario is the most likely to occur while the Upper Bound scenario is less likely, yet still plausible.

Our predictions for the new spectrum required per region are as shown in Figure 0-1.

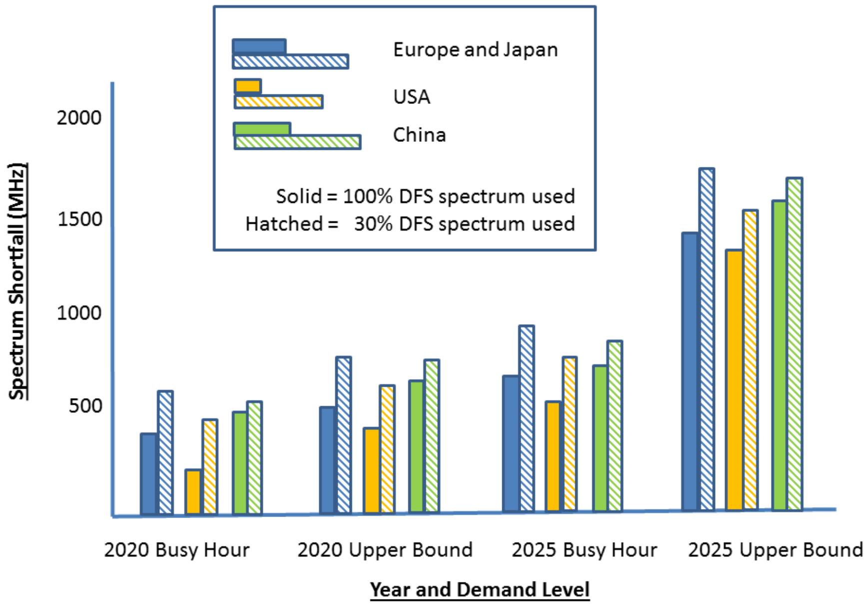

Figure 0-1 Illustration of the spectrum shortfall per region, by year and demand level.

The amount of new spectrum required varies by geographical region, and our analysis illustrates potential effects due to spectrum which is subject to local DFS requirements[1]. Our analysis assumes that new spectrum will be fully accessible by Wi-Fi.

The spectrum predictions cover the years 2020 and 2025; predicted Busy Hour and Upper Bound scenarios; two different usage levels of DFS spectrum; and three locations types consisting of office, residential and mall – of which residential was found to have the greatest spectrum requirements. Built into the predictions are technology advances, for example in terms of transmission rate, video coding improvements and device capability.

The importance of contiguous spectrum

In addition to simply needing more spectrum in total, we have shown that such spectrum needs to be assigned with sufficient contiguity such that wide channels of 160 MHz, or perhaps even wider in future, can be constructed with ease. To do otherwise would be to risk restricting the growth of Wi-Fi and the economic benefits with which it is widely associated and which was first enabled by forward-thinking spectrum regulation. Such a need for contiguity presents a significant further challenge to those with responsibility for spectrum allocation.

[1] Spectrum, access to which is determined by the constraints of Dynamic Frequency Selection procedures.

1 TRAFFIC PREDICTIONS

In this Chapter, we derive the traffic levels we will use for modelling, with reference to real-world surveys, plus predictions.

We are interested in three typical location types

- Office;
- Residential;
- Mall.

Traffic may be generated internally to the location or externally in each case. For example, traffic to and from the wider Internet is external, while traffic due, for example, to screen casting or in-band backhaul is internally generated. Both cases contribute to the loading on Wi-Fi.

1.1 External traffic predictions

External traffic relates to traffic to and from the Internet. Various surveys exist for predicted data volumes, although few, if any, go beyond five years. In order to be able to draw upon multiple sources of information, we chose to look at data from the well-known Cisco Virtual Networking Index; a regulator survey; and a commercial survey.

1.1.1 Cisco VNI predictions

The Cisco VNI forecast tool[2] was used, from which it was determined that North American consumer traffic at the household level would grow to 450 GB per month in 2020, with a growth factor of two over the five year period 2015-2020. Cisco do not predict beyond five years ahead. North America was chosen as representative of a developed area with significant broadband and Wi-Fi usage.

1.1.2 Surveyed broadband consumption

For other perspectives on data volume growth, we turned to surveyed data from a regulator, Ofcom UK, plus a commercial source. Ofcom reported a data usage of 82 GB/month for UK domestic households in 2015[3], growing at 40% per annum. In an alternative survey, Statista looked at worldwide fixed broadband usage per capita[4]. In 2014 this varied from 9.9 GB/month in Germany to 48.6 GB/month in Korea. The UK and USA were 22.3 and 18.5 GB/month, respectively. We note that the Ofcom data is per household, as is the Cisco VNI data, but the Statista data is per capita.

If 40% annual growth is maintained then this predicts 1.125 GB per person each busy hour in 2020, using the simplification that all traffic occurs during four busy hours per day, for example 7-11pm.

Beyond 2020 there are few predictions but many believe we will be some way along the likely "S" curve of demand growth, with demand growth slowing somewhat in the period 2020 – 2025. A slowing rate of growth of demand has been reported by mobile operators

[2] http://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html
[3] "Connected Nations Report 2015", from www.ofcom.org.uk
[4] See http://www.statista.com/statistics/374998/fixed-broadband-data-volume-per-capita/

over the last few years and indeed, in some extreme cases, operators such as M1 in Singapore have seen negligible growth (only 3%) in data requirements in the last year. Equally, the arrival of a new application[5] could result in a sudden increase in demand.

If, as expected, the growth begins to slow somewhat, then this would predict around 4.5 GB per person each busy hour in 2025.

1.1.3 Comparing sources of Internet data demand volumes

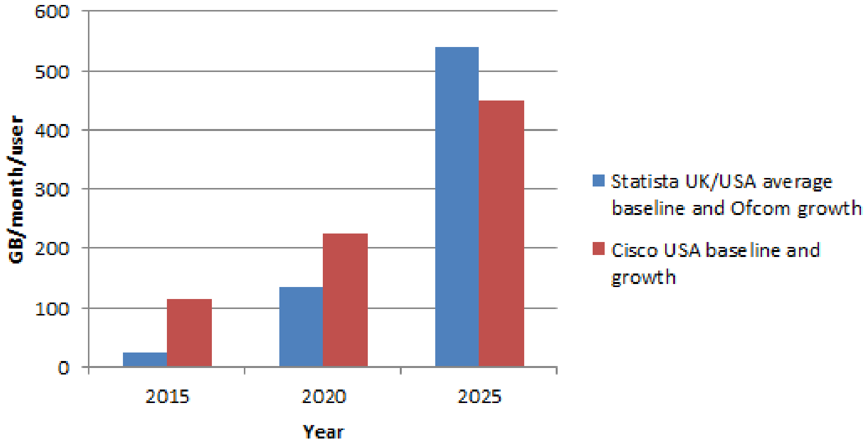

Figure 1-1 Comparison of data volumes predicted by Cisco VNI, a regulator and a commercial survey.

Figure 1-1 shows that the predictions for 2025 data volumes are broadly similar for surveyed broadband consumption from Statista / Ofcom and the Cisco VNI predictions for the USA. All figures are per user per month, having been converted where necessary. None of the data sources predict beyond 2020, so the growth factors have been extrapolated to 2025.

Cisco begins with a higher estimate of today's data volumes, but then uses a smaller growth factor, as clarified in Figure 1-2. This behaviour is the key reason that the all predictions yield similar results by 2025.

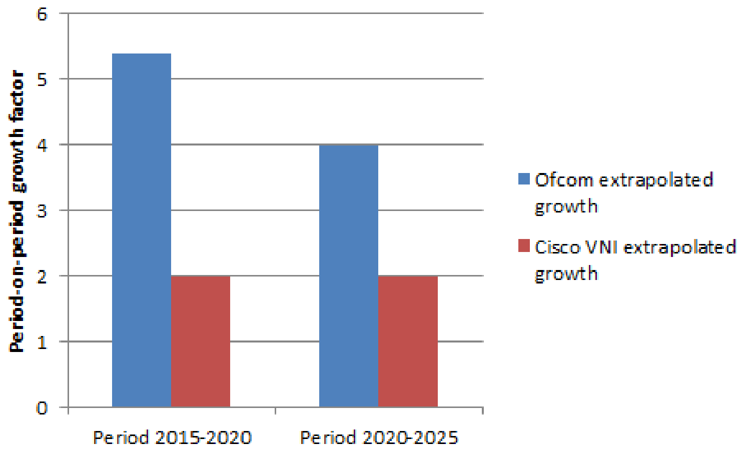

Figure 1-2 Extrapolated period-on- period growth factors for Cisco Ofcom data.

[5] For example the app-based Pokémon Go game which became extremely popular at the time of writing.

In summary, the predicted demand from the three independent sources is reasonably aligned and differences will likely not significantly affect the amount of spectrum required in 2025 since we look for multiples of 160 MHz[6].

1.2 Adapting data sources for the model

All three data sources have required extrapolation to 2025 by assuming the respective trends will continue and this represents a very significant uncertainty in our analysis. In order to address this most simply, we have normalised to an average traffic volume rounded up to 4.5 GB per person per busy hour for 2025 (since this is when estimates converge most closely) plus we have assumed that the Cisco VNI growth rates are appropriate.

Before making use of data volumes in the modelling, it is important to note that all the surveys quoted have used average growth rates. We discuss the phenomenon of growth rates more appropriate to the busy hours in Section 1.6. The surveys also relate to residential demand and we outline different assumed demands in office and mall in Sections 1.3 and 1.5 respectively. Finally we also discuss the effect of internal traffic due to in-band backhaul and soft AP[7] use such as screen casting in Section 1.4. The overall effect of these discussions is summarised per location type (office, residential, mall) in Section 1.7.

Finally, in Section 1.8, we introduce our use of two overall scenarios. One is based on the traffic volume growth predicted for the Busy Hour; the other considers a scenario where growth is greater than presently expected, i.e. even greater than the predictions using busy hour trends. The function of the latter scenario is to seek to estimate a plausible Upper Bound for the amount of spectrum which Wi-Fi may require in future.

1.3 Office versus consumer traffic

The Cisco VNI suggests that, on average, a reasonable assumption is that office traffic volume is a quarter of consumer traffic volume.

1.4 Internally generated traffic

This relates to traffic which is peer to peer within the location type considered. The prime example is screen casting in the home or in-band backhaul, where the links between APs are carried within the same frequency band as the AP-to-user traffic.

Based on our extensive experience of mesh networking[8], which is typically self-backhauled[9], we have taken a straightforward approach of doubling the residential data requirement when self-backhauling is used. Of course not all residential locations will be self-backhauled, but we have applied a pessimistic factor of two in order to also take account of those locations which may be screen casting or otherwise using soft APs.

[6] See Section 5.3 for why multiples of 160 MHz are desirable.
[7] Also known as a virtual router, where software is used to turn an end station into an access point, usually for the benefit of a particular application, such as screen casting.
[8] See, for example, "Essentials of Wireless Mesh Networking", Steve Methley, Cambridge University Press, 2009.
[9] i.e. carried in-band.

1.5 Out-of-doors Traffic

Data usage out of doors is typically much smaller than indoors. One reason is that the user is mobile and hence less likely to be using the device intensively. Measurements are difficult to find, but a recent assessment of the use of the internet out of doors has concluded that the volume of use is one tenth of the use indoors, on average[10]. We note that out-of-doors does not mean in remote locations, rather it means during normal daily life, including commuting etc. This is relevant to our mall location type.

1.6 Busy hour growth rates

The Cisco VNI and other survey data all relate to average traffic levels. But it is well-known that busy hour traffic is growing much faster, for the reason that more video traffic is included in the busy hours. Data on the difference between average and busy hour growth rates has been produced by Cisco and is shown in Figure 1-3. Busy hour growth is predicted to exceed average growth by a factor of 1.5 in a five year period.

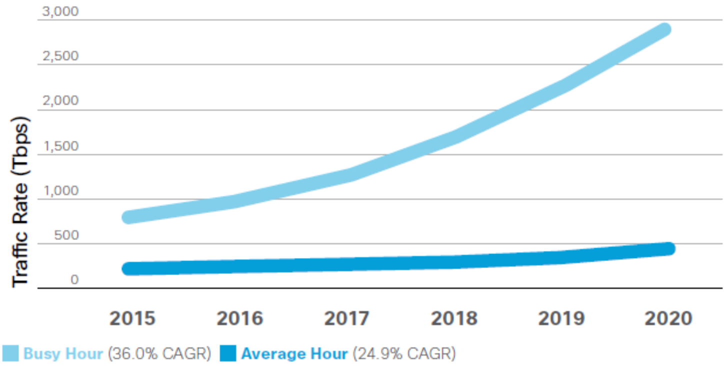

Figure 1-3 Busy hour versus average growth rates from Cisco VNI.

In our model, we take the increased growth rates of the busy hour into account, since networks must be dimensioned for busy hour rather than average volumes, and this directly affects spectrum requirements.

1.7 Demand per location type

Using the data volumes gathered from the Cisco VNI and other surveys, as described earlier, and taking into account the higher busy hour growth rate, we further double residential demand to take account of self-backhaul and screen casting as already discussed; we set office use to half the consumer value in order to accommodate the lower demand yet allow for soft APs; finally we set mall usage at one tenth of consumer demand as this is out-of-doors traffic.

1.8 Demand scenarios

We employ two scenarios, a Busy Hour Scenario based on the predictions described earlier, plus we add a scenario with higher demand. The latter demand level is greater than the predicted busy hour and was chosen to be equal to 2x the average traffic level in 2020 and

[10] "Out-of-home use of the internet", Broadband Stakeholder group, September 2014.

4x the average traffic level in 2025[11]. The higher scenario is intended to reflect what could happen if usage increased or was concentrated into fewer busy hours per day, for example. As it is intended to reflect an upper bound to spectrum requirements, we refer to it as the Upper Bound scenario[12]. Having some notion of an upper bound is likely to be helpful to those in charge of the allocation of spectrum resources.

We show the relationship of the Busy Hour scenario and the Upper Bound scenario to predicted average data volumes in Table 1-1.

Scenario	*2020*	*2025*
Busy Hour	150%	225%
Upper Bound	200%	400%

Table 1-1 The two scenarios used in the study, with their relationship to predicted average traffic volumes, for the relevant year.

In selecting an upper bound we have chosen a data volume which is less than twice the predicted busy hour volume, so it seems far from being out of the question that such volumes might occur. On the other hand it is significantly higher than any prediction we have seen reported elsewhere. Alternative estimates of an upper bound are possible, but we feel the one we have selected is reasonable.

It is worth noting that possible reasons for higher than expected data volumes include not only the obvious case of increased data demand by users, but also a case where data demand is flat on average yet becomes more concentrated into fewer busy hours per day. For example the busy hour period could decrease from the present 7-11pm to, say, 8-10pm. Networks would then have to be dimensioned to deal with peak traffic volumes which are higher by a factor of 2. Moreover, concentration effects could happen at the same time as an overall increased demand, leading to compound growth behaviour.

The data volumes used in the modelling are as follows. The detailed traffic volumes levels used for the Busy Hour scenario are shown in Table 1-2.

Busy Hour Scenario	*2020*	*2025*
Office demand	1688	5063
Residential demand	6750	20250
Mall demand	338	1013

Table 1-2 Busy Hour demand parameters (Mbytes per person during busy hour)

The detailed traffic volumes levels used for the Upper Bound scenario are shown in Table 1-3.

[11] For the purposes of comparison, this is also equivalent to a demand 30% higher than the busy hour prediction in 2020 and 78% higher than the busy hour prediction in 2025.
[12] Of course, for the avoidance of doubt, this is simply our estimate of where an upper bound might lie. In other words, it does not represent a true upper bound in the mathematical sense.

Upper Bound Scenario	*2020*	*2025*
Office demand	2250	9000
Residential demand	9000	36000
Mall demand	450	1800

Table 1-3 Upper Bound demand parameters (Mbytes per person during busy hour)

2 USE CASES AND TECHNOLOGIES

In the preceding Chapter we looked at the data volume demands expected in the future. In this Chapter we investigate the capabilities of the devices used. Again we are interested in performance expected in the future.

2.1 Most important Internet devices

The mix of devices which people use is not static, as shown in Figure 2-1. There is clearly an increase in the use of smartphones and tablets and a decrease in the use of desktops and laptops. For example, desktop use has halved over the three years of the survey and smartphone use has more than doubled. A key conclusion for our study is that smartphones have overtaken laptops as the most important way to connect to the Internet. This is true worldwide, and is even more pronounced in Asia, for example.

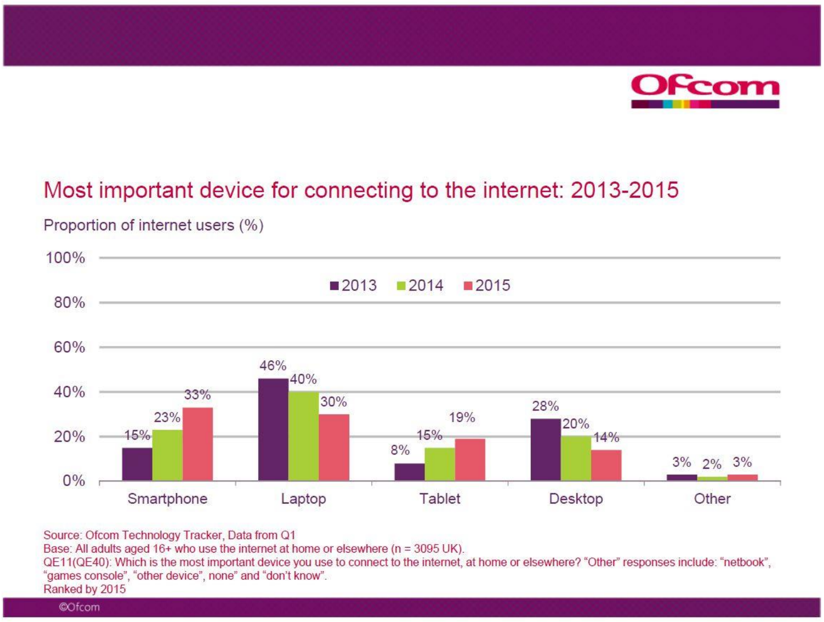

Figure 2-1 Changes in the type of device used to connect to the internet[13].

These trends are important since each type of device possesses a different level of Wi-Fi capability, which may be dictated by device size, power supply and price. We illustrate this next.

2.2 Device capabilities today

Makers of Wi-Fi access points have an interest in knowing what capabilities the clients are likely to have. Results from such a study have been published[14], which we reproduce in Figure 2-2.

[13] Ofcom Communication Market Report, 2015, available from www.ofcom.org.uk
[14] "Competitive Test Report Executive Summary - Spring 2016", available from www.mojonetworks.com

Client Make	Model	802.11 Version	Streams	Chipset Vendor	Chipset	Driver Version	OS Version
Google	Nexus 5x	11ac Wave 2	2x2	Qualcomm	QCA6174	-	Android 6.0.1
Acer	Aspire F15	11ac Wave 2	1x1	Qualcomm	QCA9377	12.0.0.203	Windows 10
OnePlus	OnePlus Two	11ac Wave 2	1x1	Qualcomm	QCA9377	-	Android 6.0.1
Apple	Macbook Pro	11ac Wave 1	3x3	Broadcom	BCM4360	7.21.94.136.1a1	MacOS 10.11.2
Dell	Inspiron 7000	11ac Wave 1	2x2	Intel	7265	18.40.0.9	Windows 10
HP	Elitebook	11ac Wave 1	2x2	Intel	7265	18.33.0.1	Windows 7
Apple	Macbook Air	11ac Wave 1	2x2	Broadcom	BCM4360	7.21.94.136.1a1	MacOS 10.11.2
Apple	iMac	11ac Wave 1	3x3	Broadcom	BCM4360	7.21.94.136.1a1	MacOS 10.11.3
Apple	iPad Pro	11ac Wave 1	2x2	Broadcom	-	-	iOS 9.2.1
Samsung	Tab S2	11ac Wave 1	2x2	-	-	-	Android 6.0.1
HP	ProBook	11n	2x2	Broadcom	BCM943228Z	6.30.223.255	Windows 10
Apple	iPad Mini	11n	1x1	Broadcom	-	-	iOS 9.3.1

Figure 2-2 Client device capabilities today[14].

Reading the data in Figure 2-2, it can be seen that low end phones and small tablets are currently 1x1 MIMO, whereas higher end phones and full size tablets are 2x2. Many laptops are 2x2, with one high end example having 3x3 MIMO today.

2.3 Projected device capabilities

We can project the device capabilities of Figure 2-2 into the future by incorporating the expected development of Wi-Fi over time.

Table 2-1 shows rates (Mb/s) versus bandwidth for different versions of 801.11 from legacy to future examples, against bandwidth used and number of spatial streams used.

Spatial streams	*Variant*	*20*	*40*	*80*	*160*
1	11b	11			
1	11g	54			
1x1	11n	72	150		
	11ac	87	200	433	867
	11ax	143	287	600	1.2 Gb/s
2x2	11n	144	300		
	11ac	173	400	867	1.7 Gb/s
	11ax	300	600	1.2 Gb/s	2.4 Gb/s
3x3	11n	216	450		
	11ac	289	600	1.3 Gb/s	2.3 Gb/s
	11ax	450	900	1.8 Gb/s	3.6 Gb/s
4x4	11n	288	600		
	11ac	346	800	1.7 Gb/s	3.5 Gb/s
	11ax	600	1200	2.4 Gb/s	4.8 Gb/s

Table 2-1 802.11 rates (Mb/s) versus bandwidth (MHz) and spatial streams.

Table 2-2 constructs a timeline of capabilities for each device type based on our understanding of when the different variants of 802.11 will be in the majority in the marketplace. For example 11n is here today, 11ac will come to dominate in the next few years and we have assumed that 11ax will become mainstream by 2025.

In terms of devices, smartphones are typically single antenna devices in the short and medium terms, apart from the larger phones, where two antennas become realistic. Laptops and tablets form a natural second group, mostly based on size where 2x2 will be most common until 2020. Premium devices are 3x3 today and are likely to become 4x4 in the next few years. We do not anticipate that client devices will have the maximum 8 antennas allowed in 11ax, even if access points do.

As far as channel width is concerned, 11n is limited to 40 MHz but we expect later 802.11 versions will concentrate on the mandated 80 MHz and the optional 160 MHz.

Device / Year	*2015*	*2020*	*2025*
Smartphone	11n 1x1 40 MHz (150 Mb/s)	11ac 1x1 80 MHz (433 Mb/s)	11ax 2x2 80 MHz (1.2 Gb/s)
Tablet/Laptop and high end phone	11n 2x2 40 MHz (300 Mb/s)	11ac 2x2 80 MHz (867 Mb/s)	11ax 3x3 80 MHz (1.8 Gb/s)
High end laptop	11ac 3x3 80 MHz (1.3 Gb/s)	11ac 4x4 80 MHz (1.7 Gb/s)	11ax 4x4 80 MHz (2.4 Gb/s)

Table 2-2 Projected 802.11 device capabilities over time.

We have made several simplifications, which include that 11ax is similar to 11ac, but with the addition of 1024 QAM (MCS 10, 11). We take into account that all rates are maxima; many are possible only at very short distances/low interference situations. The model will allow channel widths up to 160 MHz to be used where propagation conditions allow.

To complete the picture, we need to understand the distribution of device types over location types.

2.4 Device distribution per location type

We do not have precise data on which to base Table 2-3. Instead we have a number of points such as the residential data of Figure 2-1, from which we extrapolate to the office and mall location types. We expect more high-end laptops to be used in office locations and more smartphones to be used in the mall location.

Device	*Office %*	*Residential %*	*Mall %*
Smartphone	50	70	90
Tablet/Laptop and high end phone	25	30	10
High end laptop	25	0	0

Table 2-3 Projected distributions of device types as percentage per location type.

2.5 60 GHz capability

Over both scenarios in all years, we assume that the distribution of 60GHz capable users is 10%, 20% and zero in office, residential and mall locations respectively. Although all APs are assumed to be 60 GHz capable, user devices will connect at 60 GHz only if propagation conditions are suitable, leading to a lesser proportion of 60 GHz devices actually connected in office and residential location types.

The detail of this Chapter forms some of our model inputs, as we summarise in Chapter 4.

3 SHARING WITH LTE

For purposes of this study we have assumed that LTE in 5 GHz will not bring a significant amount of new traffic, but will rather take some traffic share away from Wi-Fi. Another way to say this is that we have no evidence that users will generate any more traffic because they could choose LTE over Wi-Fi in 5 GHz. Given that the proportion of traffic presently carried over LTE is dwarfed by Wi-Fi, which carries 80% and is increasing, this appears a reasonable assumption.

In terms of modelling, we do not specifically model LTE. If required it could be dealt with as a potential reduction in the number of channels available to Wi-Fi when evaluating the spectrum required.

4 SUMMARY OF KEY MODEL INPUTS

Our model requires inputs of traffic demand; device capabilities over time; distributions of device type over location types; and the dimensions of the modelled environment. This Chapter provides an easy reference to all the necessary model parameters.

We believe that where we have needed to make assumptions, they have been reasonable for the purposes of this spectrum estimation study, yet we are aware that other assumptions are possible. With this in mind our approach has been to make it clear where we have made assumptions and what these assumptions comprise.

4.1 Traffic demand levels

We have defined two scenarios of traffic demand, which are firstly a projected Busy Hour scenario and secondly an Upper Bound scenario. The latter is intended to reflect what could happen if usage increased or concentrated into fewer busy hours per day, for example. We illustrated these scenarios in Table 1-1 on page 7.

We gave modelled data volumes in Table 1-2 and Table 1-3 on page 8.

4.2 Device performance

We gave our assumed timeline of device capabilities in Table 2-2 on page 11.

4.3 Device distribution

We gave the distribution of device types in Table 2-3 on page 11.

4.4 Modelled environment

We have taken the dimensions of buildings from the IEEE 802.11 'TGax simulation scenarios'[15] for office and residential locations, plus we constructed a mall with dimensions 30m x 300m x 2 floors. Further details, including AP densities, are given in Appendix A.

We assume the office and mall location types are managed and hence use a centralised channel selection procedure, whereas this is not appropriate for residential, see Chapter 5.

[15] 11-14-0980-16-00ax-simulation-scenarios, downloaded from http://www.ieee802.org/11/Reports/tgax_update.htm

5 MODEL EVALUATION

Note that we provide a summary of the model results in terms of a table of total predicted spectrum demand in Section 5.4. A walkthrough of model operation is provided in Appendix B.

5.1 Key Performance Metrics

In evaluating the performance of a Wi-Fi system, some thought is needed as to the best metrics to use. For some users the maximum speed will be important, with too low a speed preventing some applications such as video streaming. For others, latency will be critical, causing delays in applications such as web browsing or voice. In some cases, congestion levels might impact on applications such as video conferencing by causing erratic delays.

Equally, in some cases high speeds cannot be achieved because the user is too far from the access point (AP) and so does not have a sufficiently high SNR to use higher-order modulation. This is not an issue of capacity or adequate spectrum but one of AP layout, with a denser grid of APs providing higher signal levels. The actual density used will vary from deployment to deployment and indeed more APs might be installed if sufficient users experience problems (subject to AP-AP interference considerations).

5.1.1 Capacity and utilisation metrics

For these reasons we have chosen not to focus on high speed but instead on metrics related to capacity. Specifically, we look at two key metrics; the percentage of offered traffic that is carried plus a measure of AP utilisation, based on airtime usage[16]. Both relate to data rates and latency. A network that is able to carry all the traffic offered and where the AP utilisation is within normal bounds will be able to deliver the maximum data rates that a device can access according to its signal level.

Even with these metrics there is no hard failure point at which performance changes from acceptable to unacceptable. As we have all experienced, the effect of congestion is a soft failure: Congested networks may be adequate if a little frustrating, then as loading builds the performance may degrade to become very frustrating for users and then finally degrading to the point where using the network becomes impractical.

Taking this into account, we suggest that networks should be

1. Able to carry at least 95% of the offered traffic;
2. Have an AP loading ideally below 70%.

APs with a utilisation around 70% tend to be suitable for data traffic. A lower utilisation may sometimes be suitable for more sensitive specific traffic such as voice. On the other hand, newer forms of Wi-Fi are expected to achieve lower latency at higher utilisations. Our target is 70%, which hence represents a modestly conservative approach.

5.1.2 Approach to calculating utilisation

We note that our results are specific to the location types we have simulated, which are based on IEEE 802.11 simulation scenarios. In general, adding more APs can typically

[16] We define utilisation in our airtime based model as that percentage of airtime that an AP observes as being utilised, both by itself and other neighbouring co-channel networks.

improve the situation because (1) devices are closer to an AP and so can use more efficient modulation and coding schemes and (2) more APs generally add more capacity. However, adding more APs also increases interference and so incremental improvements steadily decrease. More pragmatically, the number of APs may be limited by factors such as room size and access to backhaul. We have opted for numbers of APs that we consider practical but relatively dense. This results in a lower bound for spectrum requirements. The model is described in the Appendices.

The reporting of utilisation is complicated by our consideration of multiple frequency bands. An AP may work across the 2.4GHz, 5GHz and 60GHz bands, while devices may work across some or all of these bands. A situation could be envisioned, for example, where an AP had 5GHz and 60GHz capability but the devices within its coverage operated only on 5GHz. The AP might then appear to be 50% utilised, yet from the device viewpoint it might appear completely congested.

We have opted for an approach where we have weighted the utilisation in each band by the percentage of devices using that band. So if the 5GHz band was 80% utilised and the 60GHz band 10% utilised and if 50% of devices access each band, we would measure utilisation as (80% * 50%) + (10% * 50%) = 45%. On the one hand, in this situation, the overall AP performance might be judged acceptable but for the 50% of devices in the 5GHz band they might find usage unacceptable. On the other hand, a more complex set of multiple metrics could aim to address this, but a likely problem is that too complex a set of metrics may quickly make the results difficult to interpret.

In summary we use the approaches of

- moving terminals towards their less-preferred band when their preferred band is congested; and
- using summary measures of utilisation composed of multiple underlying measures.

5.1.3 Reporting overall utilisation

Because each deployment includes multiple APs, and because the loading can vary across them[17], then some measure of overall AP utilisation is needed. The simplest approach would be to take an average, but this might mask a situation where some APs are working well and others completely congested. To avoid this issue, we favour a cumulative distribution approach where we take the 95th percentile point. If, for example, the 95th percentile is 40% this means that 95% of all APs have a loading of 40% or less. We believe this strikes a good balance between requiring every AP to be lightly loaded and ensuring that the vast majority of users have a good experience.

[17] For example APs on the edge of a building can be subject to more external interference.

5.1.4 Traffic and utilisation versus number of channels required

In summary, we seek to identify outcomes where both

- at least 95% of the offered traffic is carried, and
- the 95th percentile of AP utilisation is below 70%.

We vary the spectrum available at 5GHz to try to satisfy these targets.

We choose 5GHz rather than other bands because

- there is limited space, if any, to expand at 2.4GHz; and
- many devices either cannot support 60GHz or will not be within range of a 60GHz AP.

Finally we note that although our choice of variable is the spectrum available at 5GHz, we could equally well have chosen bands from around 2 GHz to 10 GHz, since propagation will be similar[18]. Hence, we are not restricting the applicability of our results solely to 5GHz.

5.2 Channel selection mechanisms

We assume the office and mall location types are managed and hence use a centralised channel selection procedure[19]. We assume the residential situation is unmanaged and hence we use a random channel assignment procedure. The random assignment generally leads to a less efficient selection and an associated increase in spectrum required.

5.3 Key results

We present results relating to two time horizons and three location types

- 2020 and 2025, reflecting our expectation of two demand scenarios at each of these times as described in Chapter 1;
- office, residential and mall locations.

Offices are assumed to be multi-storey and open plan. Residential is assumed to consist of multi-story apartments which are relatively small with two occupants. The mall is assumed to be two-storey with a large central atrium. The model is described in the Appendix.

For each of the three years selected we model each environment. For each outcome we examine 95th percentile AP utilisation against the amount of 5 GHz spectrum required. The point at which our target metrics are met then determines the spectrum requirements. We assume 60 GHz penetration in devices of 10% in office, 20% in home and 0% in mall in all cases. Additionally we adopt the engineering assumption that in the future it will be more desirable to use wider channels for both speed and lower battery use in mobile devices[20].

All results presented here carried at least 95% of presented traffic. We do not model situations with fewer than 4 channels in use as this leads to excessive interference. Hence, in the following graphs, the 80 MHz channels results begin at a minimum of 320 MHz; and 160 MHz results begin at a minimum of 640 MHz of total spectrum.

---

[18] See Section 7.1.

[19] For a discussion of management and co-ordination possibilities see our earlier report "Study on the use of Wi-Fi for Metropolitan Area applications", available from www.ofcom.org.uk

[20] We note however that 160 MHz channels are not presently allowed in China.

5.3.1 **2020**

Busy Hour scenario 2020

Our busy hour scenario uses predictions of traffic demand, device capabilities over time, and distributions of device type over location for the year 2020, as summarised in Chapter 4.

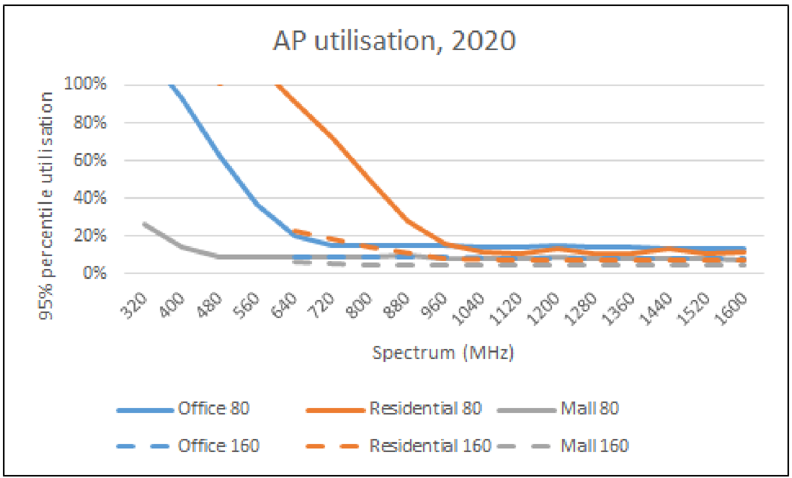

Figure 5-1 Busy Hour scenario, year 2020, using 80 and 160 MHz channels (target utilisation 70%)

From Figure 5-1 we can see that as the amount of spectrum is increased on the x-axis, then the utilisation of the AP reduces on the y-axis. In other words, greater spectrum provision leads to a less heavily loaded Wi-Fi network. Our chosen utilisation point is 70%, which was chosen as this level will facilitate normal data communication[21]. However, we note that some networks may need to run at lower utilisation in order to ensure latency requirements. In this sense our study provides a lower bound of spectrum requirements and is one reason why we also have a scenario with higher demand.

In the busy hour scenario for 2020, 800 MHz spectrum is required[22]. This is set by the residential location type which has the highest spectrum requirement.

[21] A utilisation of 70% at the 95th percentile means that 95% of APs are operating at or below 70% utilisation.
[22] All results are rounded to the next higher multiple of 160 MHz.

Upper Bound Scenario 2020

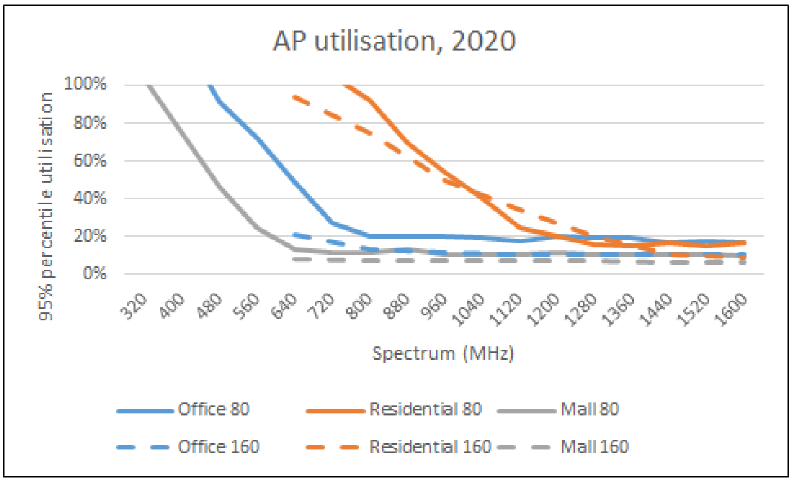

Figure 5-2 Higher Demand scenario, year 2020, using 80 and 160 MHz channels (target utilisation 70%)

Our upper bound scenario increases demand level to twice that predicted for average traffic[23] growth in 2020 and four times in 2025 (30% and 78% more traffic than the busy hour prediction), but is otherwise the same, i.e. device performance improvements and distribution over time are the same. As this higher demand level is greater than the predicted busy hour levels, it provides the potential to account for situations where more spectrum is needed because

- future demand simply outstrips the industry-based estimates we have used;
- future demand concentrates traffic further into fewer busy hours per day;
- future demand includes applications where lower network utilisation is necessary, e.g. to reduce latency.

Any or all of these situations could occur in the future.

From Figure 5-2 we can see that 960 MHz spectrum is required whether 80 or 160 MHz channels are used. This could be 12 channels of 80 MHz or 6 channels of 160 MHz. Wider channels have a potential for higher data rates. An implication is that applications which need to burst data faster will benefit from wider channels as will battery operated devices, whose lifetime will be extended by the shorter on-times facilitated by faster, wider channels.

It follows that that spectrum should be made available contiguously, specifically to suit wider channels; in this case offering spectrum in multiples of 160 MHz should be considered best practice as this offers the greatest speed potential for a user's device. For this reason, we have given spectrum demand figures which have been rounded to the next higher multiple of 160 MHz, in all cases.

Some users may have higher or lower speeds, depending on the signal quality which will depend on distance from the AP, obstructions and interference. The maximum speeds are set by the technology predicted in 2020 and summarised in Chapter 2.

[23] Surveys and forecasts generally report average traffic levels, rather than busy hour.

5.3.2 **2025**

Busy Hour scenario 2025

We repeat the graphs of the previous section, but this time for predicted demand, device performance and location distribution appropriate to 2025.

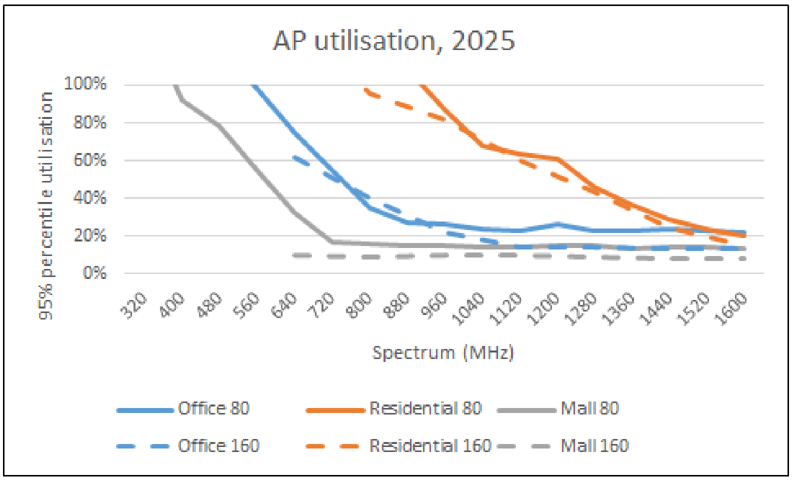

Figure 5-3 Busy Hour scenario, year 2025, using 80 and 160 MHz channels (target utilisation 70%)

In the busy hour scenario for 2025, 1120 MHz of spectrum is required to achieve an AP utilisation of 70%. Once again 160 MHz channels give the greatest opportunity for bursty high speed data usage, yet do not demand any more total spectrum than 80 MHz channels in this case.

Upper Bound scenario 2025

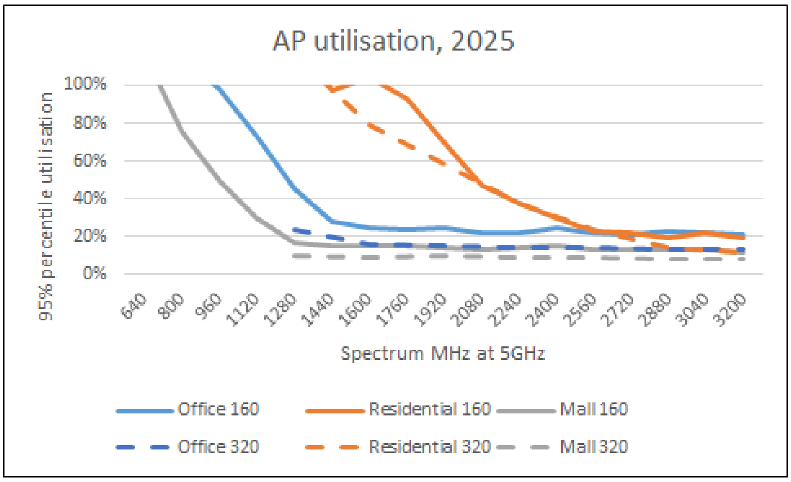

Figure 5-4 Higher Demand scenario, year 2025, using 80 and 160 MHz channels (target utilisation 70%)

In the upper bound scenario for 2025, 1920 MHz of spectrum is required to achieve an AP utilisation of 70%.

We have given all spectrum estimates as multiples of 160 MHz, in order to maximise the highest potential transmission speed[24]. We note that, although not in the 802.11 standards, in principle even wider channels may be considered in the future. This would increase the need for contiguous spectrum - although not necessarily total spectrum - and the benefit would be a higher maximum transmission speed potential.

5.4 Spectrum requirements summary

While spectrum requirements may appear modest based on busy hour growth predictions, Table 5-1 shows that the upper bound scenario calls for substantially more spectrum, especially in 2025. To avoid doubt the values in Table 5-1 represent total spectrum demand, in other words including spectrum already allocated to Wi-Fi at 5GHz[25].

Scenario	*2020*	*2025*
Busy Hour	800 MHz	1120 MHz
Upper Bound	960 MHz	1920 MHz

Table 5-1 Total spectrum required by year, for base and higher demand scenarios.

The difference between the two demand scenarios consists of relatively modest uplifts of 30% in 2020 and 78% in 2025, which we feel is far from being beyond the realms of possibility. The residential location is the most demanding in each case and hence this sets the spectrum requirements. Looking ahead to 2025 it would seem reasonable to consider investigating channels which are wider than the current maximum of 160 MHz. This would call for a greater degree of contiguous spectrum, although not necessarily more total spectrum.

5.5 Power level sensitivity analysis

Considering a general case, Figure 5-5 shows the effect of a 10dB increase or decrease in power level. This is relevant since different power restrictions exist in different regions.

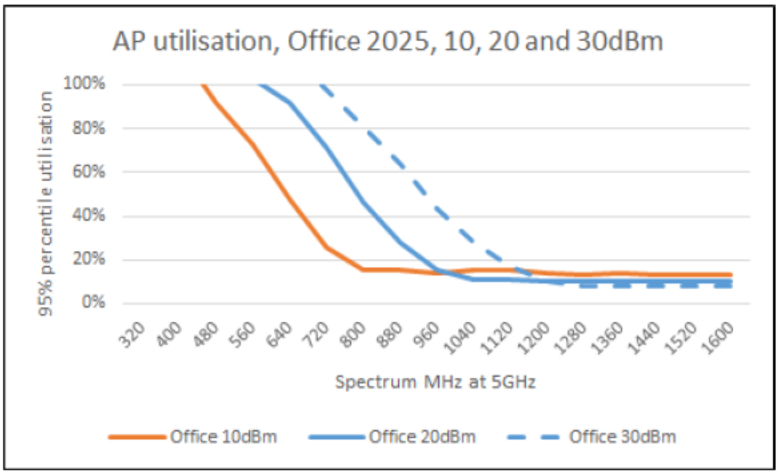

Figure 5-5 Effect of increasing or decreasing transmit power level.

[24] We note that 160 MHz channels are not presently allowed in China.
[25] See Chapter 6 for our analysis of the amount of new spectrum required, per region.

The result shows that back-off behaviour will affect throughout. In this case, reducing power will cause back-off to be triggered less, but the danger is that signal quality and hence throughput will also decrease[26]. Reducing power is thus not a panacea.

At the time of writing, the 802.11ax Task Group is discussing various methods to avoid the back-off issue, such as BSS colouring. This reduces time spent in back-off; although it does still suffer a degraded signal quality relative to a clear channel.

[26] Since noise will eventually become dominant in the signal to interference plus noise (SINR) metric.

6 SPECTRUM AVAILABILITY AND GAP ANALYSIS

6.1 Spectrum at 5GHz

Spectrum at 5GHz is of great interest. This is because the current generation of Wi-Fi, 11ac, targets 5 GHz exclusively. In turn this is driven by the exhaustion of 2.4 GHz. 11ac (and 11ax to be standardised by 2019[27]) offer a combination of range and rate that is unmatched by 2.4 GHz or 60 GHz.

There has been some movement in both Europe and the USA to extend the bandwidth available at 5GHz. However, extending the spectrum is not without its issues, especially with respect to incumbent usage in the 535-5470 MHz gap, notably EESS[28] as we evaluated in our earlier work which was submitted to ITU JTG 4-5-6-7[29]. At the top end of the band the challenge comes from co-existence with radars and potentially lower power limits.

Furthermore, some 5 GHz channels are subject to DFS (Dynamic Frequency Selection), as a way to limit interface to other band users, specifically the radio location service. This has led to an observation that channels subject to DFS may be less used than other channels. By way of an informal example, we noted an effect in Wi-Fi channel usage during simple walking surveys in central London and San Francisco[30], see Figure 6-1 and Figure 6-2.

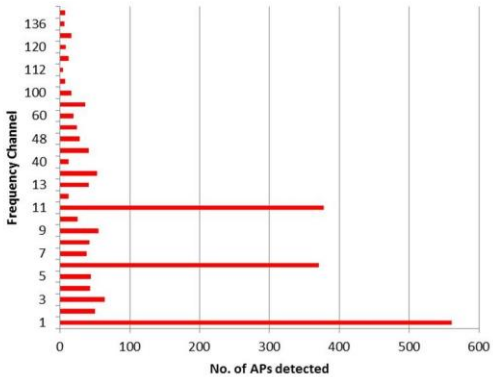

Figure 6-1 Walk survey results from London, number of APs detected per channel

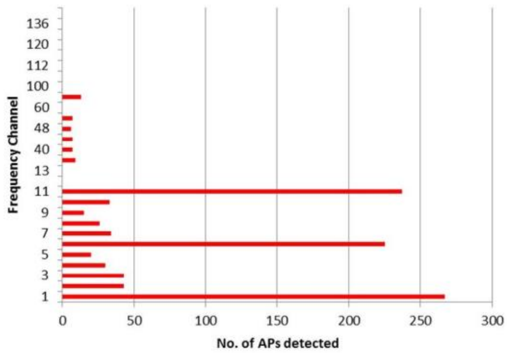

Figure 6-2 Walk survey results from San Francisco, number of APs detected per channel

[27] http://www.ieee802.org/11/Reports/802.11_Timelines.htm
[28] Earth Exploration Satellite Service.
[29] "5 GHz Co-existence Investigations: Final Report", Quotient Associates for Ofcom UK, February 2014.
[30] "Study on the use of Wi-Fi for Metropolitan Area applications", Aegis and Quotient for Ofcom UK.

Figure 6-1 from the London walk survey shows that there are more channels used in the low band of 5 GHz (channel 36 to 64) than in the high band (channel 100 and above). The effect is more dramatic in the San Francisco walk survey, Figure 6-2, where no high band usage of 5 GHz was seen at all.

We note that DFS requirements are not uniform; rather they vary by geographical region in response to the different radars used. Where a Wi-Fi AP is used globally, it must comply with each and every local DFS requirement. This adds complexity to the design.

6.1.1 Spectrum availability per region

The amount of spectrum presently available to Wi-Fi at 5GHz varies by region, see Table 6-1.

Band (MHz)	*Bandwidth (MHz)*	*Europe*	*USA*	*Japan*	*China*
5150-5250	100	Yes	Yes	Yes	Yes
5250-5350	100	Yes	Yes	Yes	Yes
5470-5725	255	Yes	Yes	Yes	No
5725-5850	125	No	Yes	No	Yes
Total bandwidth (MHz)	**580**	**455**	**580**	**455**	**325**

Table 6-1 Wi-Fi spectrum availability per sub-band and region.

Within these overall spectrum ranges, regions also differ on the requirement for DFS, see Table 6-2. In summary, while Europe and Japan are similar, other regions have not only different amounts of spectrum allocated at 5GHz, but also different proportions which are subject to DFS. We note that 5725-5850 is not currently used for Wi-Fi in Europe due to a 25mW power restriction, although FWA is allowed. This band may be opened to Wi-Fi in Europe in future.

Band (MHz)	*Europe*	*USA*	*Japan*	*China*
5150-5250	No	No	No	No
5250-5350	Yes	Yes	Yes	Yes
5470-5725	Yes	Yes	Yes	N/A
5725-5850	N/A	No	N/A	No
Total - No DFS (MHz)	**100**	**225**	**100**	**225**
Total - DFS (MHz)	**355**	**355**	**355**	**100**

Table 6-2 Wi-Fi DFS requirement per sub-band and region.

We are interested in both the total spectrum available and that proportion constrained by DFS. We may then compare this available spectrum with the total spectrum requirements we predicted for Wi-Fi in the years 2020 and 2025, in Table 5-1 on page 21.

6.2 Gap analysis

By comparison with the total spectrum requirement predictions of Table 5-1 on page 21 and the available spectrum with and without DFS constraints in Table 6-2, we can predict the spectrum shortfall per region. To be clear, this spectrum shortfall is the amount of new spectrum which will need to be found and made accessible for Wi-Fi use, if Wi-Fi is to meet the demand we predicted in the years 2020 and 2025.

We illustrate this graphically in Figure 6-3 and more precisely in tabular form in Table 6-3.

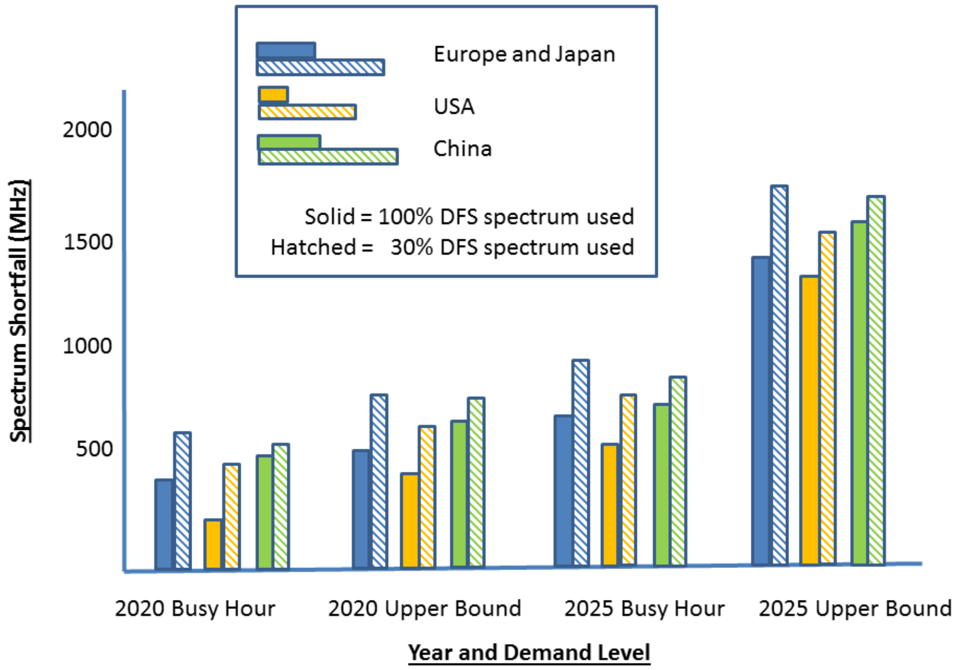

Figure 6-3 Illustration of the spectrum shortfall per region, by year and demand level.

In summary, for the year 2025, the various regions are likely to need to find between 500 MHz and 1 GHz more spectrum to satisfy the Busy Hour scenario, which reflects the widely expected growth in traffic. If demand exceeds the present Busy Hour predictions, the Upper Bound scenario suggests that an estimated maximum of between 1.3 and 1.8 GHz more spectrum may be needed. Such additional spectrum might be required due to unexpected adoption of novel applications or a further concentration of the busy hour traffic into fewer than the assumed four hours per day, for example.

While the predicted total amount of spectrum required is the same across regions (Table 5-1), the shortfall per region (Figure 6-3) depends on available spectrum. It also depends on the proportion of that spectrum which is assumed to be usable due to the effects of DFS constraints per region, as follows.

To account for the apparent under-use of DFS spectrum (see Figure 6-1 and Figure 6-2), we have assumed two cases. Firstly where all DFS spectrum is actually used and secondly where only 30% of the spectrum constrained by DFS is used. As expected, where less DFS spectrum is usable, more new spectrum is required.

It is interesting to note that, as the amount of the spectrum shortfall increases with year and demand level, the relative influence of DFS spectrum reduces. This occurs because we have chosen to assume that new spectrum will not be constrained by DFS. Clearly if any new spectrum were identified that also required DFS, then the influence of DFS constraints would no longer diminish as we have shown. In other words our assumption is that new spectrum made available for Wi-Fi will be readily accessible by Wi-Fi.

This is a very important point and we note that DFS conditions, some of which were set more than ten years ago are presently being re-examined in international fora. Given the apparent difficulties of using DFS spectrum as suggested by the walk tests, we note that removing or reducing existing DFS constraints might reduce the need to make more spectrum available for use by Wi-Fi at 5 GHz[31].

Table 6-3 contains the source data which was used to construct the graphical illustration of Figure 6-3.

Spectrum Shortfall (MHz)	*2020 Busy Hour*	*2020 Upper Bound*	*2025 Busy Hour*	*2025 Upper Bound*
Europe & Japan **- all DFS spectrum in use**	345	505	665	1465
Europe & Japan **– 30% DFS spectrum in use**	593	753	913	1713
USA **- all DFS spectrum in use**	220	380	540	1340
USA **– 30% DFS spectrum in use**	468	628	788	1588
China **- all DFS spectrum in use**	475	635	795	1595
China **– 30% DFS spectrum in use**	545	705	865	1665

Table 6-3 Spectrum shortfall per region, by year and demand level.

[31] An analysis of DFS conditions and their practical effects is beyond the scope of the present study.

7 SUBSTITUTION POTENTIAL OF SPECTRUM SUPPLY AND NEW BANDS

7.1 Spectrum characteristics

For alternative spectrum to offer a substitute for 5 GHz spectrum from the point of view of an application, it would need to offer similar propagation and data carrying ability.

For the example of 2.4 GHz, atmospheric loss is broadly similar to 5GHz; see Figure 7-1, although building penetration loss may be much higher in some materials, such as red brick for example. However, the bandwidth available is too low in practice, totalling only 83 MHz.

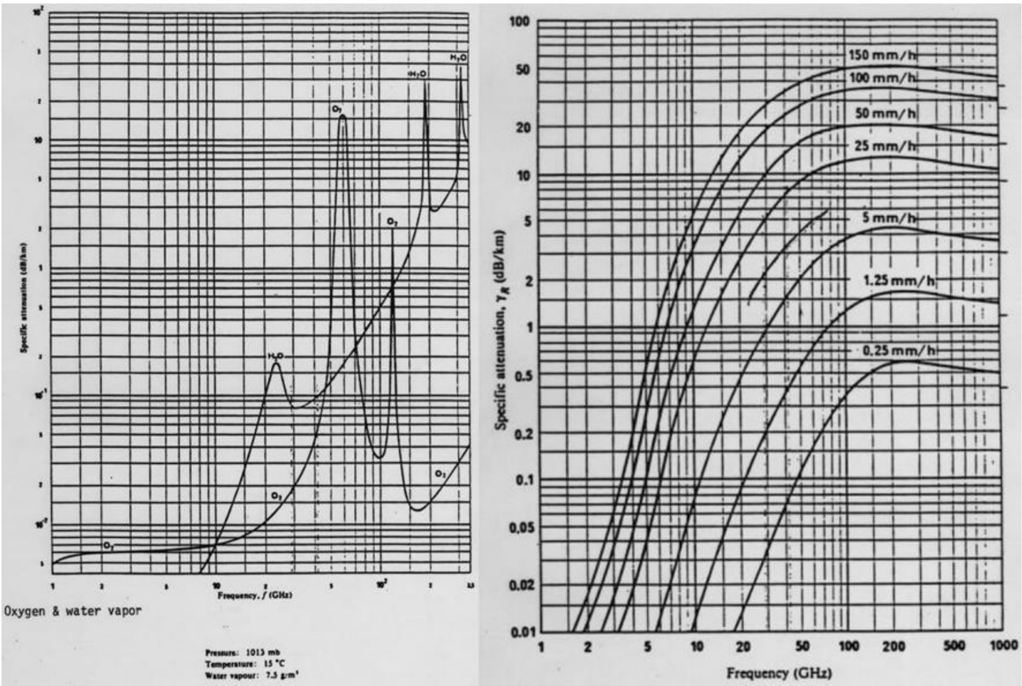

Figure 7-1 Loss due atmospheric absorption and rain fade versus frequency (FCC OET).

For the case of UHF spectrum (e.g. 700 MHz) the propagation loss is significantly smaller and self-interference would be more likely, unless powers were kept low and/or cell sizes increased. However the main problem at UHF is the limited bandwidth available compared to 5GHz. This is more a fundamental problem with UHF since it is simply not realistic to expect to use 1 GHz bandwidth at only 700 MHz.

It is an often used engineering rule of thumb that when the bandwidth required exceeds 10% of the given carrier frequency, then the design is classed as wideband and becomes significantly more challenging. We can see from the following list that more bandwidth is more easily achieved at higher carrier frequencies.

- 10% of 700 MHz = 70 MHz
- 10% of 2.4GHz = 240 MHz
- 10% of 5.5GHz = 550 MHz
- 10% of 60 GHz = 6GHz

We note that 60 GHz offers a great deal of bandwidth due to its higher carrier frequency. However the propagation and penetration with respect to 5GHz is much poorer (Figure 7-1). This makes 60 GHz suitable for small areas or short distances, plus it will not usefully penetrate walls. It is also subject to significant rain attenuation if used outdoors. 60 GHz thus cannot normally be considered a good substitute for 5 GHz. Nonetheless, there may well be a case for expanding the use of 60 GHz in order to satisfy those new and as yet uncharacterised demands such as Virtual Reality and Augmented Reality, especially if these future applications prove to be ones which tend to be used within the confines of a room (as might VR gaming, for example).

In summary, spectrum in the range 2-10 GHz may be expected to offer a reasonable degree of substitutability for 5 GHz in terms of propagation and bandwidth. This is subject of course to consideration of other users in this spectrum range, which are many and varied. The need for contiguous spectrum in order to support wide Wi-Fi channels provides a further constraint.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Future Wi-Fi spectrum requirements by region

We have shown that between 500 MHz and 1 GHz of new spectrum will be needed in 2025 to satisfy the anticipated busy hour, with between 1.3 and 1.7 GHz required if demand exceeds the busy hour prediction by a relatively modest 78%, for example due to novel and as yet un-anticipated applications, or the further concentration of traffic into fewer busy hours than the present four hours per day. The amount of new spectrum required varies by geographical region, and our analysis illustrates potential effects due to spectrum which is subject to local DFS requirements[32]. Our analysis assumes that new spectrum will be fully accessible by Wi-Fi.

Our predictions for the new spectrum required per region are as shown in Figure 8-1[33].

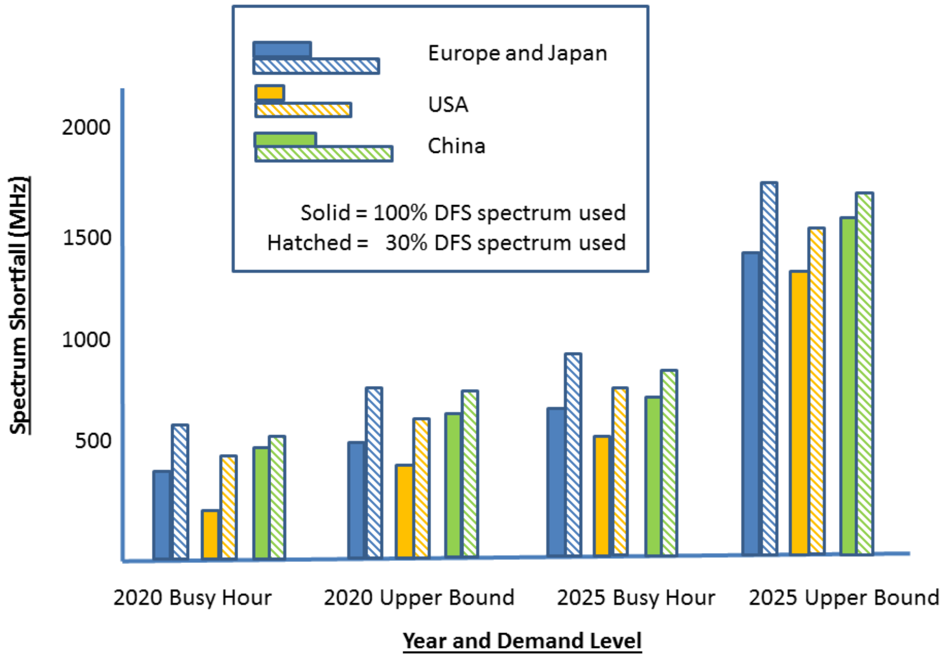

Figure 8-1 Illustration of the spectrum shortfall per region, by year and demand level.

The spectrum predictions cover the years 2020 and 2025; predicted Busy Hour and Upper Bound demand levels; two different usage levels of DFS spectrum; and three locations types consisting of office, residential and mall – of which residential was found to have the greatest spectrum requirements. Built into the predictions are technology advances, for example in terms of transmission rate, video coding improvements and device capability.

8.2 The importance of contiguous spectrum

In addition to simply needing more spectrum in total, we have shown that such spectrum needs to be assigned with sufficient contiguity such that wide channels of 160 MHz, or

[32] Spectrum, access to which is determined by the constraints of Dynamic Frequency Selection procedures.
[33] See also Table 6-3 on page 27.

perhaps even wider in future, can be constructed with ease[34]. To do otherwise would be to restrict the growth of Wi-Fi and the economic benefits with which it is widely associated and which was first enabled by forward-thinking spectrum regulation. Such a need for contiguity presents a significant further challenge to those with responsibility for spectrum allocation.

[34] Where regulation allows.

9 APPENDIX A: MODEL PARAMETERS

Number of channels: 2.4GHz – 3; 5GHz – variable; 60GHz – 3.

Transmit power: 20dBm.

Path loss coefficients: see Appendix B.

Channel bandwidths: 2.4GHz – 20MHz, 5GHz – variable, 60GHz – 2160MHz.

Percentage use of 60GHz: Office – 10%, Residential – 20%, Mall – 0%.

Machines per person = 3.

Noise rise above thermal: 2.4GHz – 15dB, 5GHz – 10dB, 60GHz – 10dB.

Dimensions of buildings: IEEE 802.11 office and residential location types[35], plus the mall with dimensions 30m x 300m x 2 floors.

Access points per floor: AP density is set in m^2 and the user density also in m^2.

> 1 AP per $100m^2$ in office and residential and 1 per 150 m^2 in mall.
>
> 1 person per 10 m^2 in office, 1 per 25 m^2 in residential and 1 per 7 m^2 in mall. So e.g. 4 people per AP in residential

Data volumes: variable.

[35] 11-14-0980-16-00ax-simulation-scenarios, downloaded from http://www.ieee802.org/11/Reports/tgax_update.htm

10 APPENDIX B: MODEL STRUCTURE

10.1 Model structure (pseudo code)

Define environment

- Set x and y dimensions of floor;
- Set number of floors;
- Set average distance between interior walls;
- Set average wall loss and average floor loss;
- Set access points per floor;
- Set users per floor;
- Set data rate requirements per user in MB over busy hour.

Place access points

- Place APs on even rectangular grid across floor;
- For each band in use;
  - For office and mall assign frequencies across access points based on available number of channels using algorithm where successive APs look for lowest interference channel and grab it.
  - For residential assign frequencies randomly.

Place users

- Place users on even rectangular grid across floor.

Place machines

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Calculate max data rates based on SINR per user

- For each band in use
  - Find closest access point on same floor;
  - Calculate path loss to serving access point and hence SNR;
  - Calculate path loss to every other access point using same frequency and add interference levels;
  - For those APs where the interference level is above the threshold then assume that terminals will back-off.
  - Add in assumed levels of non-Wi-Fi interference;

- Use look-up tables to convert to data rates.

Calculate transmission time per user as % of total time assuming perfect balancing of load across band[36]s.

Add total transmission times per access point.

Build histogram of congestion.

[36] We define utilisation in our airtime based model as that percentage of airtime that an AP observes as being utilised, both by itself and other neighbouring co-channel networks.